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A

HANDBOOK OF ROCKS,

FOR USE

WITHOUT THE MICROSCOPE.

BY

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WITH A

GLOSSARY OF THE NAMES OF ROCKS

AND OF OTHER

LITHOLOGICAL TERMS.

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PREFACE.

The clear presentation of the subject of rocks to beginners is not an especially simple undertaking. The series of objects is extremely diverse, and many unrelated processes are involved in their production. In order not to confuse and bewilder students, the teacher must emphasize the intelligible points and the recognizable characters, avoiding alike distinctions that have their chief foundations in past misconceptions, such as the time element in the classification of igneous rocks, or that require microscopic study to substantiate them. In the following pages the attempt has been made to avoid these difficulties, and only to mention and emphasize the characters that a beginner, properly equipped with the necessary preliminary training in mineralogy, can observe and grasp.

Some years of annually going over this ground have convinced the writer that for this purpose we are not likely to reach a more serviceable, fundamental classification than the time-honored one of Igneous, Aqueous (or Sedimentary) and Metamorphic rocks. They furnish not alone convenient central groups, but also prepare the student for subsequent geological reading. With the Aqueous have been placed the Eolian as a similar, although very minor division, so that fire, water and air, the ancient elementary agents, are emphasized in their work upon the earth, and the fundamental classification is based, as it should be, on method of origin. The only illogical step involved is the placing of the breccias together with the sediments, but breccias are so subordinate and go so conveniently with conglomerates that it has been done.

The igneous rocks are the ones that present the greatest difficulties to the learner. In the following pages, after a preliminary exposition of principles, the very minor group of the volcanic glasses is first taken up, because it is the simplest and because it illustrates cooling from fusion most forcibly. Passing then through the felsitic and porphyritic to the granitoid textures, rocks of increasing complexity are one after another attacked. Analyses have been freely used to illustrate the chemical differences of magmas, because in no other way can the varieties be fundamentally described. Within fairly narrow limits the chemical composition of the magma establishes the mineralogy of the rock.

The Aqueous and Eolian rocks are not difficult to understand. The Metamorphic are in many respects the most obscure of all, but it is hoped that enough varieties have been selected and emphasized to serve for field use and for the reasonably close determination of the great majority of those that will be met in Nature.

Many names will be encountered in geological reading that are not mentioned in the book proper. To explain them and to avoid confusing the main text with unessential matter, they have been compiled in a Glossary. Practically all the names for rocks will be found there, and some related geological terms. The chief guide in its preparation has been the index of Zirkel's great *Lehrbuch der Petrographie*, but not a few American terms are introduced, which are not in it nor in Loewinson-Lessing's *Petrographisches Lexikon*, to which the writer is also greatly indebted. Other works, English, French and American, have likewise been at hand. One only needs to compile a glossary to appreciate what numbers of unnecessary and ill-advised names for rocks burden this unfortunate branch of science, and to convince one that the philological petrographer comes near to being the enemy of his kind.

So far as possible, technical words of classic derivation have been avoided in the main work in favor of simple English, and for the rocks described, American type have been especially sought with which to illustrate the different species, because they are more significant and accessible to readers on this side of the ocean. The text except the glossary, appeared as a series of papers in the SCHOOL OF MINES QUARTERLY during 1895–96.

J. F. K.

AUGUST, 1896.

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ABBREVIATIONS.

A. A. A. S., or Proc. Amer. Assoc. Adv. Sci.—Proceedings of the American Association for the Advancement of Science.

Amer. Geol., or A. G.—American Geologist.

Amer. Jour. of Sci., or A. J. S.—American Journal of Science, sometimes called Silliman's Journal.

Bull. Geol. Soc. Amer.—Bulletin of the Geological Society of America.

Bull. Mus. Comp. Zoöl.—Bulletin of the Museum of Comparative Zoölogy, Harvard University, Cambridge, Mass.

Jahrb. d. k. k. g. Reichs.—Jahrbuch der kaiserlichen, königlichen, geologischen Reichsanstalt., Vienna, Austria.

Jour. of Geol.—Journal of Geology, published at the University of Chicago.

Neues Jahrb., or N. J.—Neues Jahrbuch für Mineralogie, Geologie und Palæontologie, Stuttgart, Germany.

Quar. Jour. Geol. Soc., or Q. J. G. S.—Quarterly Journal of the Geological Society of London.

Tsch. Mitth.—Tschermak's Mineralogische und Petrographische Mittheilungen, Vienna, Austria.

U. S. Geol. Surv.—United States Geological Survey, Washington. The publications are Bulletins, Monographs and Annual Reports.

Zeits. d. d. g. Ges.—Zeitschrift der deutschen geologischen Gesellschaft, Berlin, Germany.

Zeits. f. Krys.—Zeitschrift für Krystallographie, Munich, Germany.

ERRATA.

P. 15, line 21. Alternations, not alterations.
P. 17, line 14. Usually, not unusually.
P. 17, line 14. Has, not have.
P. 35, line 1. Anal. 7. Weed and Pirsson, not Pirsson.
P. 35, line 24. Weed and Pirsson, not Pirsson.
P. 36, Anal. 7, reference. Gänge, not gäuge.
P. 41, line 15. Early Tertiary, not pre-tertiary. Headline andesites, not andecites.
P. 48, line 10. Tonalite is a quartz-mica-hornblende diorite. It is more correctly defined in the glossary.
P. 50, line 18. Presence not presenec.
P. 51, line 34. Kimberlite, not kimberleyite.
P. 66. Reference to analysis 1 is wrong. The rock is a damourite slate. See p. 108, reference to anals. 5.
P. 77, line 31. IV., not III.
P. 77, line 34. 1, not 38.
P. 84, line 19. Rocks, not works.
P. 88, line 26. 108, not 423.
P. 133. Insert

Diabase-porphyrite, a porphyrite whose ground-mass is a finely crystalline diabase, and whose phenocrysts are prevailingly plagioclase. It is contrasted with augite-porphyrite, whose phenocrysts are prevailingly augite.

Diorite-porphyrite, a porphyrite whose ground-mass is a finely crystalline diorite, and whose phenocrysts are prevailingly plagioclase. It is contrasted with hornblende-porphyrite, whose phenocrysts are prevailingly hornblende.

A HAND BOOK OF ROCKS.

FOR USE WITHOUT THE MICROSCOPE.

CHAPTER I.

INTRODUCTION. ROCK-FORMING MINERALS. PRINCIPLES OF CLASSIFICATION.

A rock may be best defined as any mineral or aggregate of minerals that forms an essential part of the earth. The word mineral is used because this is our most general term for all inanimate nature, and while the lifeless remains of organisms often contribute in no small degree to rocks, no rock is made up of those which are still alive. In instances a single mineral forms a rock, but among minerals this is the exception. By far the greater number are in such small amount that they cannot properly be considered rocks. Rock-salt, ice, calcite, serpentine, cemented fragments of quartz, kaolin and a few others are in sufficient quantity, but the vast majority of rocks consist of two or more. The condition that a rock should form an essential part of the earth is introduced to bar out those minerals or aggregates which, though important in themselves, are none the less insignificant as entering into the mass of the globe. Thus the sulphide ores, while locally often in considerable quantity, when broadly viewed are practically neglectable. Yet this is somewhat arbitrary and there are single minerals and aggregates that may properly give rise to differences of opinion. The following pages err, if at all, on the side of demanding that the amount should be large. A rock must also have an individual character, sufficient to establish its identity with satisfactory sharpness. The species cannot be marked off with the same definition as in plants, animals or minerals, and there is here again reasonable opportunity for differences of opinion as to the limits which should be set, some admitting of finer distinctions and greater multiplicity of species than others; but after all has been said, there should be a well marked individuality to each rock species such that any careful and qualified observer may readily see. Too great refinements and too minute subdivisions ought to be avoided.. The determining conditions of species will be taken up at greater length when the preliminaries of classification have been set forth, but it must be appreciated that the point of view is also a most important factor. Thus if one is studying the geology of a district with close accuracy, and is tracing out the history and development of its rocks with microscopic determinations and descriptions of minerals and structures which may be minute, finer distinctions will naturally be drawn than those that suggest themselves to one who is engaged in ordinary field work or in mining or engineering enterprises. It is for the latter class that these pages are prepared and throughout the descriptions and classification here given, the necessary limitations and the practical needs of such observers are always kept in mind. Textural and mineralogical distinctions are alone emphasized where easily visible on a specimen, although never made contradictory of principles of origin and classification that could be carried to greater length and subdivision.

Rocks embrace matter in a great variety of structures and conditions. While in general we picture them to ourselves as solid, yet under the terms of our definition, we have no logical right to bar out liquids or even gases. The physical condition may vary with ordinary temperatures. Thus we cannot reject ice as an extremely abundant and important rock, and yet its solid condition results from water with a moderate loss of heat, and at ordinary temperatures the same molecules may be in a liquid or gaseous state. All that we know of volcanoes indicates that liquid, molten magmas exist for long periods deep in the earth, yet they are none the less rocks because of their liquidity. In general, however, rocks are solid, and gases or liquids (except water) deserve no further attention. In texture rocks may be loose and incoherent as in sand, gravel, volcanic dust and the like, or they may be extremely dense, hard and solid, as in countless familiar examples. This solidity or massiveness has its limitations, for all observation and experience show that what are apparently solid masses are really broken up by multitudes of cracks into pieces of varying size. All quarries and mines have these, and they may aid or annoy the operators according to the purposes of excavation. They will again be referred to at length. Rocks are also in all cases permeated with minute pores and spaces that admit of the penetration of water and other liquids, especially if under pressure. These are important factors in terrestrial circulations.

THE CHEMICAL ELEMENTS IMPORTANT IN ROCKS.

The chemical elements really important in rocks are comparatively few, and are those which are most widespread in nature. The best estimate that has been made is that of F. W. Clarke, in Bulletin 78, of the U. S. Geological Survey, pp. 34–43. The crust to ten miles below sea level and the air and the ocean are embraced. The composition of the solid crust is reached by averaging up analyses of igneous and crystalline rocks, 880 in all; 321 from the United States, 75 from Europe, 486 from all quarters. Igneous rocks being the source of all the others, furnish the best data for the general chemistry of the globe. The composition of the ocean is then averaged in with that of the rocks on the basis of 7% for the former and 93% for the latter, with a further addition of 0.02% for the nitrogen of the atmosphere. Other ingredients, as the oxygen of the air are less than 0.01% and are neglected.

O	49.98	Na	2.28	P	0.09
Si	25.30	K	2.23	Mn	0.07
Al	7.26	H	0.94	S	0.04
Fe	5.08	Ti	0.30	Ba	0.03
Ca	3.51	C	0.21	N	0.02
Mg	2.50	Cl, Br	0.15	Cr	0.01

The remaining elements may be omitted in this connection, although, as a moment's reflection will show, they include all the common metals except iron and manganese.

There is good ground for believing that toward the centre of the earth the metallic elements become much more abundant, and that near the centre some of the heaviest known are in excess, but these inferences, however well-based, concern materials far beyond actual experience, and of no great moment in this connection. As regards rocks we have to deal with the outer portions of the globe, to which we are accustomed to refer as the crust. This term is not meant to indicate anything as to the condition of the interior, but merely its exterior as contrasted with the inner parts.

The chemical elements above cited are combined, except perhaps in volcanic glasses, in the definite compounds that form mineral species. These compounds change, more or less, in the course of time, under the action of various natural agents, chief of which are water, carbonic acid and oxygen, but at any particular stage, however complex the rock may be, it is made up of definite chemical compounds, though we may not be able to recognize them all. The most important compounds are not numerous and are practically limited to the following: silicates, oxides, carbonates, sulphates, chlorides, and of far inferior moment phosphates, sulphides, and one native element graphite.

As a broad conception in speaking of these compounds it is in many respects advantageous to have the igneous rocks primarily before our minds, because as stated above they are the sources of the others. In taking up the minerals the purpose here is to emphasize their chemical composition and relative importance, not to describe them as would be done in a text-book on mineralogy so as to enable a student to recognize them, for such preliminary knowledge is here assumed. Our purpose is to make prominent the chief chemical compounds entering into the earth, and to prepare the way for a true conception of the range and relations of its constituent rocks.

THE SILICATES.

THE silicates are grouped as follows: the feldspars and feldspathoids; the pyroxenes; the amphiboles; the micas; olivine. The last four groups are often collectively called the ferro-magnesian silicates. Zircon and titanite conclude the list of those important in igneous rocks. In addition there are a number of others that are specially characteristic of altered or metamorphosed rocks, viz: epidote, scapolite, garnet, tourmaline, topaz, andalusite, cyanite, fibrolite or sillimanite, and staurolite. Finally a few hydrated silicates complete the list.

THE FELDSPARS and their related minerals are all double silicates of alumina and an alkali or an alkaline earth or both. We speak of them as alkali-feldspar, potash-feldspar, soda-feldspar, lime-soda feldspar, etc. based on this fact. They are generally grouped as orthoclase, representing monoclinic feldspar with its two cleavages at right angles (hence the name), and as plagioclase or triclinic feldspar, with oblique cleavages, and one striated cleavage plane. Orthoclase is chiefly $KAlSi_3O_8$, but Na replaces more or less of the K, without affecting the crystal system. Sufficient amounts of soda are however capable of changing the system to triclinic and the feldspar is called anorthoclase. Microcline is also a triclinic variety of potash feldspar, with a cleavage angle slightly less than a right angle, but with peculiar and characteristic optical properties, which are chiefly of moment in microscopic work. The clear, unclouded orthoclase of the later volcanic rocks is often called sanidine. It does not differ essentially from the orthoclase of the older rocks, and the distinction based on geological age is obsolete, but as the terms are still used in the literature of the subject it is well to understand them.

The plagioclase feldspars embrace a practically unbroken series from pure soda-alumina silicate in albite, $NaAlSi_3O_8$, to pure lime-alumina silicate, anorthite, $CaAl_2Si_2O_8$. Various mixtures of these two molecules give the intermediate species, but the two on which special stress is ordinarily placed are oligoclase, with soda in excess and hence called soda-lime feldspar, and labradorite with lime in excess and hence called lime-soda feldspar. If we represent the orthoclase molecule, $KAlSi_3O_8$ by Or; the albite molecule, $NaAlSi_3O_8$ by Ab, and the anorthite, $CaAl_2Si_2O_8$ by An, all the intermediate feldspars can be algebraically expressed. Thus anorthoclase lies between Ab_2Or_1, and $Ab_{4.5}Or_1$, Albite embraces those from Ab through Ab_8An_1; oligoclase, Ab_6An_1, through Ab_2An_1; (the intermediate mixtures Ab_3An_2 through Ab_4An_3 are called andesine); labradorite includes Ab_1An_1 through Ab_1An_2; bytownite Ab_1An_3—Ab_1An_6; anorthite Ab_1An_8 to An. This conception of feldspars as isomorphous mixtures of molecules is a very valuable one and by determining specific gravity, optical properties and chemical composition, one or all, the different members can be identified. Practically, however, in the ordinary determination of rocks, aside from microscopic work we are forced by the difficulty of distinguishing the intermediate varieties, into the general use of orthoclase and plagioclase, and we rely on the presence or absence of the striations peculiar to the basal cleavage of the latter in distinguishing between the two, but of course experience and familiarity with the general characters and associations of minerals in rocks often enables one to determine very closely the minor varieties. We would naturally look for orthoclase, albite and oligoclase in acidic rocks or those high in silica, while in basic rocks we would expect those near the anorthite end.

All the feldspars have very similar crystal forms when these are developed, as they occasionally are in rocks. When they are small and irregularly bounded, cleavage faces should be sought out and examined with a pocket lense. It is interesting to note that only in igneous rocks do we obtain crystals uniformly developed on all sides, for only in a fused magma do they swim and grow without a fixed support.

The word feldspar is spelled by English writers "felspar," but among Americans the more correct form, based on the etymology, is employed, following the German original "Feldspath."

FELDSPATHOIDS. With the feldspars are placed two other important and closely related minerals, nepheline and leucite, to which may also be added one that is quite rare, melilite. *Nepheline* is an hexagonal soda-alumina silicate $4Na_2O,4Al_2O_3,9SiO_2$, in which some of the Na_2O is replaced by K_2O and CaO. It appears in a subordinate series of igneous rocks that are rich in soda. *Leucite* is an isometric potash silicate, $K_2O,Al_2O_3,4SiO_2$, with a little Na_2O replacing part of the K_2O. It appears as an important rock-making mineral in the igneous rocks of ten or fifteen localities the world over, and is therefore of very limited distribution. *Melilite* is an extremely basic lime-alumina silicate, $12CaO,2Al_2O_3,9SiO_2$, and appears in a few rare basalts.

Reference may also be made to sodalite, nosean and haüyne which are occasionally met, but which are chiefly of microscopic interest.

The feldspars, together with the feldspathoids nepheline and leucite, are the most important of the rock-making minerals in their relations to the classification of rocks.

In order to have a standard series of analyses with which to compare those of rocks later given, the following table is inserted of theoretical feldspars and feldspathoids. The relative amounts of the several oxides will suggest the extent to which the molecules are present in any rock whose analysis is known:

	OR ORTHOCLASE $KAlSi_3O_8$	AB ALBITE $NaAlSi_3O_8$	AN ANORTHITE $CaAl_2Si_2O_8$	NEPHELINE $Na_8Al_8Si_9O_{34}$	LEUCITE $KAlSi_2O_6$	MELILITE $Ca_{12}Al_4Si_9O_{36}$
SiO_3	64.7	68.6	43.1	45.0	55.0	38.1
Al_2O_3	18.4	19.6	36.8	34.3	23.5	14.5
K_2O	16.9				21.5	
Na_2O		11.8		20.7		
CaO			20.1			47.4

Recalling what has been said about the replacement of the alkalies by one another, and that we never meet any of these minerals chemically pure, according to the formulas above given, and making suitable allowance for this replacement, we may still appreciate that orthoclase and albite, being high in silica, favor acidic rocks, and the others being low in silica, basic ones; that nepheline implies a magma rich in alumina and soda, leucite one rich in potash, and melilite one low in silica and alumina, but high in lime.

THE PYROXENES and the AMPHIBOLES are best described together. Each embraces a series of compounds of the same chemical composition, differing only in physical and optical properties. As the table shows they vary from magnesia silicate through a series of lime and lime-alumina silicates, with an iron silicate generally present. All the pyroxenes have a prismatic cleavage of nearly 90° (87°10′ or thereabouts), while the amphiboles cleave along a prism of nearly 120° (124°11′).

COMPOSITION.	PYROXENE.	AMPHIBOLE.	SYSTEM.
$MgOSiO_2$ $FeOSiO_2$	Enstatite Bronzite Hypersthene	Anthophyllite	Orthorhombic
$CaMgSi_2O_6$	Diopside	Tremolite	Monoclinic
$CaFeSi_2O_6$	Malacolite	Actinolite	
$MgAl_2SiO_6$	(Diallage)		
$MgFe_2SiO_6$	Augite	Hornblende	
$FeAl_2SiO_6$			
$NaFeSi_2O_6$	Acmite	Arfvedsonite	
	Aegirine		

Under the orthorhombic pyroxenes enstatite has least of the molecule $FeOSiO_2$, *i. e.* FeO less than 5%, bronzite has FeO less than 14% and hypersthene the higher values. The increase brings about a darker color and changed optical properties. The orthorhombic pyroxenes are much less frequent than the monoclinic, but are of wide distribution, especially hypersthene. The orthorhombic amphiboles are of minor importance and are but seldom met.

The light-colored monoclinic pyroxenes are almost pure lime magnesia silicates, and are called diopside. They are chiefly found in crystalline limestones. As iron increases, they pass into malacolite, which may also contain small amounts of the aluminous molecules. Neither of these pyroxenes is of special abundance as a rock maker. When pinacoidal cleavages around the vertical axis appear in addition to the prismatic ones in pyroxenes of the general composition of malacolite they are called diallage and are important in some igneous rocks. But the chief rock-making pyroxenes are the dark aluminous, ferruginous ones, which are called augite, and these are among the most important of all minerals in this connection. The igneous rocks rich in soda, in which nepheline is common, are the ones that contain acmite and ægirine, the soda-pyroxenes.

The monoclinic amphiboles are closely parallel in their occurence and relations to the pyroxenes. Tremolite is met in crystalline limestones. Actinolite may form schistose rocks by itself, but much the most important variety is hornblende, the aluminous variety corresponding to augite. The soda amphibole arfvedsonite is rare.

The pyroxenes and amphiboles are often collectively referred to as the bisilicates, the oxygen of the base being to the oxygen of the silicon, as shown in the first two formulas, in the ratio of 1 : 2. It is also interesting to note that many blast furnace slags are calculated on the basis of the formulas for pyroxene.

THE MICAS. The commonest of these is biotite and its distribution is very wide. It is a complex silicate involving magnesia in large amounts and is often called magnesia mica for this reason. The other bases are hydrogen, potassium, iron and aluminum, and the general formula is $(H, K)_2 (Mg, Fe)_2 Al_2Si_3O_{12}$. It is important in its bearings on the classification of rocks. Phlogopite is of related composition but is almost entirely limited to crystalline limestones. Muscovite, from its richness in potash, is often called potash mica. It is widespread in granites and schists and as an alteration product. Its general formula is $(H, K) Al SiO_4$.

OLIVINE, the unisilicate of magnesium and iron, $2(Mg,Fe)O SiO_2$, completes the list of silicates which are of the first order of importance in igneous rocks. The above name is usually employed in preference to chrysolite. Olivine is practically limited to basic igneous rocks.

Zircon and titanite are interesting microscopic accessories, but as rock-making minerals they are seldom visible to the naked eye.

Along the contacts of intrusions of heated igneous rocks, and in regions where the original sediments have undergone strong dynamic disturbances, with oftentimes attendant circulations of waters more or less heated, a series of characteristic silicates is in each case developed. Garnet, tourmaline, topaz, andalusite, scapolite and biotite are especially characteristic of the former; garnet, cyanite, sillimanite, staurolite, biotite, and muscovite of the latter. Epidote results when feldspars and the ferro-magnesian silicates undergo decay and alteration in proximity, so that the solutions afforded may react on one another.

The hydrated silicates of chief importance include a magnesian series, embracing talc and serpentine, which result from the ferro-magnesian minerals; a ferruginous aluminous series, with much iron oxide, usually collectively called "chlorite," and derived from the iron-alumina silicates; and finally kaolin, the hydrated silicate of alumina that is chiefly yielded by feldspar. Zeolitic minerals are also often met, but rather as vein fillings and in amygdaloidal cavities than as important rock makers.

The oxides include quartz and its related minerals chalcedony and opal, and the oxides of iron—magnetite and hematite and the hydrated oxide, limonite. With these should be mentioned chromite and ilmenite (menaccanite), which are of minor importance. Quartz is found in all rocks high in silica. Magnetite and hematite are at times almost abundant enough to constitute rocks themselves. They favor igneous and metamorphic varieties when present in a subordinate capacity. Magnetite is the most widespread of all the rock-making minerals. Limonite is an alteration product. Chromite is practically limited to the basic igneous rocks and their serpentinous derivatives. Ilmenite is a common accessory in many igneous rocks.

The carbonates are calcite, dolomite and siderite, all three being really members of an unbroken series from pure carbonate of calcium, through admixtures of magnesium carbonate to pure magnesite on the one hand, or with increasing carbonate of iron to pure siderite on the other. The sulphates of moment are anhydrite and gypsum, the latter the hydrous, the former the anhydrous salt of lime. The one chloride is the sodium chloride, rock salt or halite, and the one phosphate is apatite, the phosphate and chloride of lime. The two sulphides of iron, pyrite and pyrrhotite are the only ones sufficiently widespread to deserve mention, and graphite is the chief representative of the elementary substances, although native sulphur might perhaps with propriety be also mentioned.

We speak of minerals as essential and accessory, meaning by the former term those that constitute a large part of the rock, and that must be mentioned in the definition; by the latter those that are present in small amounts or that are more or less fortuitous. Primary minerals are those that date back to the origin of the rock, as for instance the ones that crystallize out from a molten magma as it solidifies; secondary minerals are formed by the alteration of the primary. Feldspars, pyroxene and hornblende are good illustrations of the former; hydrated silicates of the latter.

THE PRINCIPLES UNDERLYING THE CLASSIFICATION OF ROCKS.

Rocks must of necessity be classified in order to place them in their natural relations so far as possible and to allow of their systematic study. At the same time they are so diverse in their nature and origin that the subject is not an easy one. They must however be grouped on the basis of their structures and textures; or of their mineralogical composition; or of their chemical composition; or of their geological age; or of their method of genesis. One or several of these principles enter into all schemes. On the basis of the first, rocks have been classified as massive and stratified; as crystalline and fragmental or clastic, each with subdivisions on one or more of the other principles. On the basis of the second we have had those with only one mineral (simple rocks) and those with several (complex rocks). The chemical composition as shown by a total analysis (bausch-analysis) without regard to special mineral components is of almost universal application in a subordinate capacity. It must be regarded in the group of igneous rocks and in those that are deposited from solution, chiefly highly calcareous or highly siliceous rocks. The principle of geological age was formerly much valued in connection with igneous rocks, but it is a thoroughly exploded one. The principle of origin or genesis is the most philosophical of all as a fundamental basis, but while in the greater number of cases it may be readily applied there are some puzzling members whose entire geological history is not well understood. Very early in the development of the subject it was appreciated that there were two great, sharply contrasted groups, according as they had consolidated and crystallized from a molten condition or had been deposited in water either as mechanical fragments or as chemical precipitates. Widened observation, especially in arid and sandy regions, has added to these a less important group of those whose particles have been heaped together by the wind. They are called the eolian rocks and will be taken up together with the aqueous, with which they have many points in common. Two grand divisions have therefore been established, the igneous, on the one hand, and the aqueous and eolian on the other.

Even a limited field experience soon convinces the observer that many rocks are encountered which cannot be readily placed with either of the two great classes whose origin is comparatively simple. Rocks for instance are met having the minerals common to the igneous, but with structures that resemble those of sediments in water.

Great geological disturbances, especially if of the nature of a shearing stress, may so crush the minerals of any igneous rock and stretch them out in bands and layers as to closely imitate a recrystallized sediment. The baking action of igneous intrusions on fine sediments, such as clays and muds, makes it difficult for an observer, without the aid of thin sections and a microscope to say where the former sediment ends and the chilled magma begins. Sediments buried at great depths and subjected to heat and hot water become recrystallized with their chemical elements in new combinations. These excessively altered rocks have been often grouped into a separate, so-called " metamorphic " division, which was a sort of " omnibus " of unsolved geological problems. This metamorphic group is useful, and the term is a common one in the science, but wherever possible it is well to appreciate the true affinities of its members which though altered are still referable to their originals.

In the following pages these three divisions will be adopted, but the metamorphic group will be reduced to a minimum by remarking, in connection with descriptions of the unaltered, changes that igneous and aqueous undergo.

We take up, therefore, in this order:

A. The Igneous Rocks.

B. The Aqueous and Eolian Rocks.

C. The Metamorphic Rocks.

CHAPTER II.

GENERAL INTRODUCTION TO THE IGNEOUS ROCKS. CLASSIFICATION.

The Igneous rocks are first treated because they have been the originals, according to our best light, from which all the others have been directly or indirectly derived, for either from the fragments, as afforded by their decay, or from the mineral solutions, yielded by their alteration, possibly in the primitive history of the globe, all the others have been produced.

The igneous rocks occur in dikes, sheets, laccolites, bosses and vast irregular bodies, for which we have no single term. Dikes (spelled also dykes) have penetrated fissures in other rocks, and have solidified in them. They therefore constitute elongated and relatively narrow bodies, of all sizes, from a fraction of an inch in thickness and a few feet in length, to others a thousand or more feet across and miles in length. Sheets are bodies of relatively great lateral or horizontal extent, compared with their thickness. They are either surface flows, which may be afterwards buried or else are intruded between other strata. In the last case they are often called laccolites, especially if lenticular in shape. Roughly tubular masses, such as might chill in the conduit of a volcano are called necks. Irregular, projecting, rounded bodies are called bosses. The enormous masses of crystalline rocks like granite that often cover hundreds of square miles, and that frequently appear to have fused their way upward by melting into their substance, overlying rocks, are called bathylites. They have in most, if not all instances, only been uncovered by erosion, for the name means a rock belonging to the depths of the earth. It will be later brought out that the character of the occurrence, whether as dike, surface flow, intruded sheet, or bathylite, has an important influence on the texture.

Igneous rocks are characteristically massive, as contrasted with the stratified structure of the sedimentary, and the term massive is sometimes employed as a synonym of igneous. Other synonymous terms are eruptive and anogene, both meaning that the rocks have come up from below. Many years ago the distinction was made between those that have crystallized deep within the earth, the plutonic and those that have been poured out on the surface, the volcanic. The words intrusive and effusive or extrusive have been employed in much the same way. Between surface flows and deep-seated masses (bathylites) and their characteristic textures, every gradation is to be expected and is met, and an intermediate group has even been established by some writers for rocks that have cooled as intruded sheets and dikes. This three-fold distinction is not carried out here, the two extremes being believed to illustrate the varieties satisfactorily when accompanied by auxiliary remarks on the intermediate types.

We are tending more and more to employ the word structure to describe the larger features of a rock, as for instance a massive structure as against a stratified, while the smaller features are described as textures, as for instance a glassy texture, a porphyritic or a granitoid, terms that refer to characters which may be seen even on a small fragment. Glassy texture, as the name implies, is that of glass or slag and has no definite minerals. It results when a molten magma is so quickly chilled that the minerals have no opportunity to form. Porphyritic implies larger crystals, well formed or corroded and rounded, embedded in a more finely crystalline, or even in a glassy " ground-mass." There may be several sizes and kinds of these crystals, and because of their prominence in the rock they are called phenocrysts, *i. e.*, apparent crystals, but phanerocryst is better etymologically. If a magma crystallizes as a mass of very fine or microscopic crystals without phenocrysts, its texture is described as felsitic. A granitoid or granular texture has the component crystals all about the same size, and very seldom possessing their own crystal boundaries. Strictly speaking, there is no groundmass in granitoid rocks. Sometimes from a local abundance of mineralizers (as later explained), granitoid rocks have small cavities into which the component minerals project with well bounded crystals. Such are called *miarolitic*.

Textures in igneous rocks are due to several factors that have influenced the development of the magma during its consolidation.

The most important are chemical composition, temperature, rate of cooling, pressure and the original presence of dissolved vapors called mineralizers. The fusibility varies with the *chemical composition*. The most acid or siliceous magmas, *i. e.* those with 65–75% SiO_2 are least fusible. When molten they are viscid and ropy. The fusibility increases with the decrease of silica down to the basic rocks with 40 to 50% SiO_2. The ultra-basic rocks which graduate into practically pure bases, as in some rare, igneous iron ores are less fusible. This statement that acid rocks are least fusible often puzzles a student who is familiar with blast furnace practice and the composition of slags, in which the most siliceous are regarded as most fusible, but slags themselves as a comparison of analyses will readily show are to be paralleled with basic rocks. The importance of the fusibility as regards textures lies in the fact that the highly siliceous quickly chill, become ropy and freeze. They therefore especially yield glasses. The easily fusible remain fluid to lower temperatures, crystallize out as minerals to a greater degree and seldom yield glasses. They flow farther from the vent and tend to develop the porphyritic or even a variety of granular texture. The influence of *temperature* has been partly outlined in speaking of composition, but it will readily appear that in its progress to the surface a basic magma might stand for a considerable period at a temperature of fluidity, whereas an acid magma in the same situation would consolidate. The *rate of cooling* is important. Cooling magmas tend to break up into minerals. As a general thing it requires a very quick chill to prevent their formation. Hence it is that even volcanic glasses which appear to be perfect glass to the eye are shown to be full of dusty, microscopic minerals under the microscope. Volcanic glasses are chiefly found on the outer portions of flows or dikes, but instances are known where sheets of them are very thick, as at Obsidian Cliff in the Yellowstone Park. The common experience with lavas is that certain crystals develop to notable size, it may be an inch or more in diameter, while the magma stands beneath the surface, in circumstances favorable to their formation. These are then caught up in the moving stream and brought to the surface or near it where the final consolidation takes place and fixes them in the so-called ground mass. A quick chill makes a fine-grained groundmass when not a glassy one, a slow cooling yields one more coarsely crystalline, but in the final cooling or consolidation at or near the surface, crystals are seldom if ever developed of a size commensurable with those formed in the depths. By this process of partial crystallization below and final consolidation on the surface, the porphyritic texture is almost always developed, but in strict accuracy it should be stated that cases are known where phenocrysts appear to have formed in lavas after coming to rest. Magmas also flow to the surface with no phenocrysts (or "intratelluric" crystallizations) and then consolidate not as glass, but as finely crystalline aggregates, practically all groundmass. The resulting texture is called felsitic.

Pressure, such as is developed upon a magma deep within the earth or during its passage to the surface is thought to exert an influence upon the formation of many phenocrysts and to be necessary for their development. *Dissolved vapors*, such as steam, hydrofluoric and boracic acids are also important factors. Acidic magmas are more generally provided with them than basic, and where locally abundant they lead to variations both in the mineral composition and texture at different places in the consolidated rock. They may prevent the development of glass, and cause a sheet such as Obsidian Cliff, in the Yellowstone Park, to present alterations of glassy and stony layers, the latter being formed of microscopic crystals.

A word should be added about the chemical composition of rocks and about the interpretation of analyses before the rocks themselves are taken up. The analyses are reported in percentages of oxides, for the most part, and these are arranged in the following series, SiO_2, Al_2O_3, Fe_2O_3, FeO, CaO, MgO, Na_2O, K_2O, H_2O. In order to have anhydrous materials, it is customary to ignite and determine loss on ignition. This loss includes both H_2O and CO_2 and where large throws uncertainty over the relations of the elements left behind, because of the evident advance of decay. Small percentages of other oxides are quite invariably present and in refined work are determined. These are TiO_2, MnO, NiO, BaO, SrO, S, Cl, P_2O_5, Li_2O, and even rarer ones. They are however always in very small quantity. We often recast an analysis, by dividing, as in the determination of a mineralogical formula, each percentage by the molecular weight. We thus get numerical molecular ratios which indicate the relative numbers of individual molecules and enable us to draw conclusions as to the way they are combined with one another in the component minerals. Variations in chemical composition entail variations in resulting minerals, but it is also true that the same magma, if consolidating under different physical conditions of heat, pressure, etc., at different times may yield somewhat different minerals, for instance, hornblende instead of augite, or vice versa. A study of analyses soon makes one more or less familiar with the minerals that would necessarily result. The more important points are the amounts of silica, of the alkalies and alkaline earths, of iron oxides and of alumina. For instance, as a rule only magmas high in SiO_2, yield quartz, for otherwise it would combine with the bases. Much K_2O is necessary for an orthoclase or leucite rock, but much Na_2O for one with nepheline. MgO in relatively large amount is required to yield olivine or an orthorhombic pyroxene, and when feldspars drop away and rocks become very basic we expect high CaO, MgO, FeO, Fe_2O_3, and low SiO_2. In rocks tested as building stone, the significance of sulphur is important and very little should be present, for it indicates pyrites. It should never reach 1 %.

The specific gravity or density of a rock is an important feature in its practical bearings. While it may in ice be less than 1, and in coals and certain carbonaceous deposits drop as low as 1.25, and in very porous sandstones reach 2.25, yet in the common rocks it is seldom below 2.50, and ranges from this to over 3.00. Granites are usually about 2.65, but basic rocks, rich in iron, attain to the higher limits, even above 3.0. Determinations are important in those rocks used for building purposes, and are expressed in pounds per cubic foot.

Of recent years we have come to regard molten magmas as essentially solutions of some compounds in others, and to appreciate that solutions do not cease to be such, even when the temperature is very high. It results from this that the crystallization of the minerals of an igneous rock takes place from the magma as this in its cooling successively reaches a point of saturation for the salt in question. The least soluble thus separate the earliest of all, and then the others in order; but as the pressure under which they rest is also a factor, and this is subject to variation, as indeed is the temperature during movement to the surface, one mineral's period of formation may overlap another's more or less. The order of formation will be determined by the laws of thermodynamics and necessarily the mineral that develops the most heat in crystallizing will be the first to develop. As a general rule, the relations of the minerals in rocks show that the earliest to form are apatite; the metallic oxides (magnetite, ilmenite, hematite); the sulphides (pyrite, pyrrhotite); zircon and titanite. These are often called the group of the ores. Next come the ferromagnesian silicates, olivine, biotite, the pyroxenes and hornblende. Next follow the feldspars and feldspathoids, nepheline and leucite, but their period often laps well back into that of the ferromagnesian group. Last of all, if any excess of SiO_2 remains, it yields quartz. In the variation of the conditions of pressure and temperature just referred to, it may and does often happen that crystals are again redissolved in the magma, or are resorbed, as it is called; and it may also happen that after one series of minerals, unusually of large size and of intratelluric origin, have formed the series is again repeated on a small scale as far back as the ferromagnesian silicates. Minerals of a so-called second generation thus result, but they are always much smaller than the phenocrysts, and are characteristic of the groundmass.

It results from what has been stated that the residual magma is increasingly siliceous up to the final consolidation, for the earliest crystallizations are largely pure oxides. It is also a striking fact that the least fusible minerals, the feldspars and quartz, are the last to crystallize.

In the matter of the study and determination of a rock species, especially of an igneous rock, it is desirable to procure materials as fresh and unaltered as possible. If feldspars have all changed to kaolin and clay, and if ferromagnesian silicates are merely chlorite or serpentine, and if secondary quartz, calcite and the like have formed, it is very difficult if not impossible to draw correct or even well-grounded inferences. Rocks near ore bodies are very often of this character.

Bearing in mind these differences of texture and the causes of them, it is possible to group igneous rocks in such arrangement that they can be intelligently studied, and identified with a reasonably close approximation to the truth. It should be appreciated, however, that with finely crystalline rocks, whose components are too small for the unassisted eye, the microscope is the only resource, and with this as an aid much greater subdivision can be attained. The object here in view is to limit the discussion purely to the study without the microscope.

ACIDIC ⟵ BASIC ⟶

IGNEOUS ROCKS

Glassy	Acid Glasses, Obsidian, Perlite, Pumice, Pitchstone.			Andesite Obsidian.			Basic Glasses, Scorias, Tachylyte, Basalt-Obsidian.				
	Chief Feldspar Orthoclase.			Chief Feldspar Plagioclase.				Nepheline, Leucite	No Feldspar		Ultra-basic Rocks.
	Biotite (or) (and) Hornblende (or) (and) Augite			Biotite (or) (and) Hornblende		Pyroxenes		A series of rare basaltic rocks	Augite (or) (and) Hornblende (or) (and) Biotite		
	Quartz	— Quartz	Nepheline or Leucite	+ Quartz	— Quartz	— Olivine	+ Olivine		— Olivine	+ Olivine	
Felsitic and Porphyritic	TRACHYTE GROUP			ANDESITE GROUP		BASALT GROUP					Basic Segregations in normal Magmas. Meteorites.
	Rhyolite (Quartz-Porphyry) (Quartz-Felsite)	Trachyte (Porphyry) (Felsite)	Phonolite (rare) Leucite-Phonolite (very rare)	Dacite (Porphyrite)	Andesite (Porphyrite)	Augite-Andesite Olivine-free Basalt (Diabase)	Basalt Dolerite (Olivine-Diabase)	with Nepheline, Leucite (seldom Melilite), one or all. Not readily distinguished from Basalt without the microscope. Extremely rare in America.	Augitite Not readily distinguishable from Basalt. Extremely rare in America.	Limburgite	
Fragmental	Rhyolite Tuff and Breccia	Trachyte Tuff and Breccia	Phonolite Tuff and Breccia	Andesitic Tuffs and Breccias		Basaltic Tuffs and Breccias					Water.
Granitoid	GRANITE GROUP		Nepheline Syenite (rare) Leucite-Syenite (very rare)	DIORITE GROUP		GABBRO		Theralite (extremely rare)	GROUP		Ice.
	Granite (Pegmatite)	Syenite (rare)		Quartz-Diorite (Tonalite)	Diorite	Diabase Gabbro Anorthosite Norite	Olivine-Diabase Olivine-Gabbro Olivine-Norite		Pyroxenite	Peridotite	
SiO_2	80–65%	65–55%	60–50%	70–60%	65–50%	55–45%		45–38%	55–40%	45–30%	30–0%

The scheme of classification of the igneous rocks has three principles underlying it, viz: texture, mineralogical composition and chemical composition. The textures are five, glassy, felsitic, porphyritic, fragmental and granitoid, and the table is arranged from top to bottom so that they come in this order. The arrangement is adopted because it brings the glassy which are the simplest of all rocks at the outset, where they can be best taken up by the beginner. The rocks are arranged from left to right on a mineralogical principle, and chiefly on the basis of the predominant feldspar present, as is the usual custom. This also makes possible a general succession from those most acidic on the left to those most basic on the right, but while this is true for the extremes it is not strictly so for intermediate points because dacites and quartz-diorites are far higher in silica than are phonolites and nepheline-syenites, and even than trachytes and syenites. The general range of silica is indicated on the lowest line. At the same time the importance of the bases is not to be overlooked and subsequent tables of analyses are given so as to show the range.

The general and larger truths of igneous rocks are fairly well brought out in condensed tables of this character, although exceptional cases are known that would require its modification. But no attempt has been made to confuse the larger truths by mention of the rarer occurrences, for, as before stated, only ordinary examination is assumed in connection with this text. When rare and exceptional varieties are met they should be placed in the hands of a microscopical worker. It should also be appreciated in connection with the table that groups of rocks shade into one another by imperceptible gradations and that they are not marked off with the sharpness of ruled spaces. In general the glassy, felsitic and porphyritic constitute the *lavas* or surface flows, the dikes and the laccolites, while the granitoid rocks are the deep-seated, or abyssal ones, but there are cases where the latter show porphyritic tendencies and others wherein the former shade into granitoid textures.

CHAPTER III.

THE IGNEOUS ROCKS, CONTINUED. THE GLASSES. THE ROCKS WHOSE CHIEF FELDSPAR IS ORTHOCLASE. THE PHONOLITES AND NEPHELINE-SYENITES.

THE GLASSES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO.	CaO.	MgO.	K_2O	Na_2O	Loss.	Sp. Gr
1.	79.49	11.60	0.33	0.49	1.64	0.09	1.52	4.04	0.68	
2.	76.20	13.17	0.34	0.73	0.42	0.19	4.46	4.31	0.33	2.352
3.	75.52	14.11	1.74	0.08	0.78	0.10	3.63	3.92	0.39	2.342
4.	74.70	13.72	1.01	0.62	0.78	0.14	4.02	3.90	0.62	2.345
5.	74.05	13.85	tr.	. .	0.90	0.07	4.31	4.60	2.20	
6.	74.05	12.97	2.73	. .	0.12	0.28	5.11	3.88	0.22	2.37
7.	74.01	12.95	. .	1.42	0.99	0.48	4.65	5.34	0.29	2.391
8.	72.87	12.05	1.75	. .	1.30	1.10	tr.	6.13	3.00	
9.	71.6	12.0	1.0	. .	1.1	0.2	4.3	2.5	7.4	
10.	71.56	13.10	0.66	0.28	0.74	0.14	4.06	3.77	5.52	
11.	65.13	15.73	2.24	1.86	3.62	1.42	3.96	2.93	2.43	
12.	60.5	19.1	4.2	0.3	0.6	0.2	3.5	10.6	. .	2.48
13.	54.28	14.83	14.73	. .	7.02	3.65	1.27	4.22	. .	2.704
14.	50.82	9.14	7.33	7.03	11.63	7.22	1.02	3.06	1.74	2.66
15.	45.73	20.15	12.46	. .	8.67	3.59	4.11	5.74	0.12	

1. Pumice, Cinder Cone, Calif., J. S. Diller, Bull. 79, U. S. G. S., p. 29. 2. Black Obsidian, Tewan Mtns., N. M., J. P. Iddings, 7th Ann. Rep. U. S. G. S., 219. 3. Red Obsidian, Yellowstone Park, J. P. Iddings, 7th Ann. Rep. U. S. G. S., 219, also FeS_2 0.11. 4. Black Obsidian, Yellowstone Park, J. P. Iddings, 7th Ann. Rep. U. S. G. S. 219, also FeS_2 0.40. 5. Scoriaceous Obsidian, Mono Lake, Cal., I. C. Russell, 8th Ann. Rep. U. S. G. S., 380. 6. Obsidian, Lipari Is. Abich. Vulk. Ersch. 62. 7. Obsidian from Andesite, Clear Lake, Cal., G. F. Becker, Mon. XIII., U. S. G. S. 104. 8. Perlite, Hungary, Kalkowsky, Elemente der Lith. p. 75. 9. Pitchstone, Meissen, Lemberg, Z. d.d. g. G. XXIX 508. 10. Pitchstone, Silver Cliff, Colo., W. Cross, Phil. Soc. Wash. XI. 420. 11. Andesitic perlite, Eureka, Nev. Hague. Mono. XX. U. S. G. S. 264. 12. Phonolite obsidian, Teneriffe, Abich, Vulc. Ersch. 62. 13. Hyalomelane, Ostheim, Germany, Lemberg Z. d. d. g. G. XXXV. 570. 14. Pele's Hair, Hawaii, Cohen N. J. 1880, II. 41. 15. Tachylyte, Gethurms, Germany, Lemberg, See No. 13.

Comments on the analyses. An examination of the table of analyses indicates that the magmas are high in SiO_2, and relatively low in all other bases except the alkalies. The high Na_2O of Number 12 is worthy of remark, because this is the rule with a nepheline rock. The percentages under the column headed loss, which practically indicate the H_2O present are characteristic for different varieties. They are low in the case of obsidians, Nos. 2, 3, 4, 6, 7; unusually high in No. 5, described by Russell as scoriaceous obsidian; still higher in the perlites Nos. 8, 11; and reach a maximum in the pitchstones Nos. 9 and 10.

Basic glasses are seldom sufficiently free from included crystals as really to be separable from the porphyritic rocks. Frothy and cellular crusts, do however, appear on lava streams, and are known as scorias, and rare, homogeneous glasses have been called tachylyte and hyalomelane.

Varieties. The chief glasses are obsidian, pumice, perlite and pitchstone. The name obsidian, is applied to homogeneous glasses with low percentages of water. The word is of classic and ancient origin and is now used with a prefixed name for all glasses, such as rhyolite-obsidian, basalt-obsidian, etc. Pumice is an excessively cellular glass, caused by expanding steam bubbles. Perlite is a glass broken into small onion-like, individual masses, by concentric cracks, from contractions in cooling. The concentric, shelly masses lie in between intersecting series of larger, straight cracks; the perlites have considerable water, usually 2–4%. The word is also written pearlstone, and was suggested by the fancied resemblance of the concentric shells to the familiar gem. Pitchstone is a homogeneous glass, like obsidian, but contains 5–10% of water. Pitchstones have often a more resinous appearance than obsidians, but there is no very essential difference apparent to the eye. The name was formerly used for glasses of earlier geological age than the obsidians. Obsidians are usually black or red, with translucent edges; pitchstones are mostly reds and greens, but thin slivers are practically colorless; all the glasses contain dusty, embryonic crystals, gas pores, and sometimes skeleton crystals of larger growth, and even a few phenocrysts which are often arranged in flow lines and swirling eddies. Almost all large developments of the glasses show dense, stony or lithoidal layers, and streaks, that are due to the development of minute crystals of feldspar and quartz, which may be arranged in radiating rosettes, called spherulites. The individual crystals are not often large enough to be seen with the unassisted eye. Expanded, bubblelike cavities are also met, with perhaps several concentric walls, on which at times are perched little well-formed crystals. These cavities are called lithophysæ, *i. e.*, stone bubbles. Topaz, quartz, tridymite, feldspars, fayalite and garnet have been found in beautiful crystals in them. The lithophysæ are due to the influence and escape of mineralizers, and may reach a diameter of over an inch.

Relationships.—The glasses are all mere varieties of volcanic rocks, which a quick chill has prevented crystallizing. At the same time, it is only possible by field associations or by chemical analysis to refer them to their corresponding porphyritic types, although in the great majority of cases they are formed from rhyolitic magmas.

Geological Occurrence.—The glasses sometimes appear as independent sheets and dikes; more often they are on the surface of well crystallized lava-sheets or on the outer portions of dikes.

Alteration.—Glasses resist alteration notably well, but in the long run are subject to decay along cracks and exposed surfaces. They yield quartz, kaolin and fine, scaly muscovite. In instances they devitrify, as it is called, or break up into aggregates of quartz and feldspar in excessively minute crystals, so that we can only trace them back to the original glass, by the flow lines, spherulites, etc., that still remain. Such devitrified forms have been called by F. Bascom, apobsidian. Petrosilex is an older term applied to these and other similar rocks, and felsite has been also used.

Distribution.—The glasses are widespread in the West. Obsidian Cliff, in the Yellowstone Park, yields black, red and stony varieties, and has been made a type locality by the studies of J. P. Iddings. Silver Cliff, Colorado, has furnished some remarkable pitchstones, described by Whitman Cross. The extinct volcanoes of New Mexico, Utah, Montana and around Mono Lake, California, are well known localities. Alaska has supplied much from near Fort Wrangel, and in Mexico and Iceland are other prolific sources. Along the Atlantic Coast there are only the devitrified glasses of ancient (pre-Cambrian) volcanoes. These are well developed in New Brunswick, Maine, Massachusetts and Pennsylvania. Abroad the obsidian of the Lipari Islands is a famous one, and the perlites of Hungary supply the usual type specimens in our collections. The best known of all pitchstones are found at Meissen, near Dresden, in Saxony, and on the island of Arran, off the west coast of Scotland.

THE RHYOLITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	83.59	5.42	tr.	tr.	3.44	tr.	1.37	5.33	0.76	2.54
2.	78.95	10.22	3.23	. .	1.84	0.14	1.76	4.18		
3.	77.5	9.7	6.1	. .	. .	. .	5.8	0.3	0.4	
4.	75.20	12.96	0.37	0.27	0.29	0.12	8.38	2.02	0.58	
5.	73.91	15.29	. .	0.89	0.77	. .	4.79	3.62	1.19	
6.	73.07	11.78	2.30	. .	2.02	0.39	6.84	1.19	2.24	
7.	71.12	14.58	1.69	. .	1.50	0.15	6.01	3.26	0.95	
8.	70.92	13.24	3.54	0.66	1.42	0.23	4.25	4.28	0.57	
9.	70.74	14.68	0.69	0.58	4.12	0.28	2.59	2.29	2.09	2.68
10.	68.84	15.73	. .	3.11	3.58	0.90	3.59	2.89	1.50	2.4
11.	68.10	14.97	2.78	1.10	3.04	1.10	2.93	3.46	1.28	2.636
12.	67.20	14.95	5.19	. .	0.30	2.39	0.89	4.00	2.13	
13.	66.91	14.13	5.00	. .	2.35	0.95	5.40	3.86	1.42	
14.	66.60	16.69	2.06	0.93	1.40	1.15	5.23	2.46	1.70	2.43
15.	63.63	17.42	0.15	5.76	2.86	. .	5.54	4.52	0.15	

1. Soda-rhyolite, Berkeley, Cal. Palache. Bull. Geol. Dept. Univ. Calif. I. 61. 2 Rhyolite. Iceland, Băckström, Contrib. to Icelandic Liparites. 3. Rhyolite, Wales, A. Harker, Bala Volc. Ser. 13. 4. Rhyolite, Silver Cliff, Colo. Cross. Colo. Sci. Soc. Dec. 5, 1887, 229. 5. Rhyolite, Pinto Peak, Eureka, Nev. A. Hague, Mono. XX., 264. 6. Rhyolite, McClelland Peak, Washoe Dist., Nev. F. A. Gooch, Bull. 17, U. S. G. S. 33. 7. Rhyolite, Island of Ponza, near Naples. Quoted by Kalkowsky, Elem. d. Lith., p. 75. 8. Rhyolite, Yellowstone Park. Idding's Origin Igneous Rocks, Tab. 1. 9. White Porphyry, Leadville, Colo., Cross, Mono. XII., U. S. G. S. 326. 10. Rhyolite, Lassen's Peak, Cal., Fortieth Paral. Survey I. 652. 11. Gray Porphyry, Leadville, Colo., Mono. XII. U. S. G. S. 332. 12. Quartz Porphyry, Flagstaff Hill, Colo., Palmer & Fulton, Colo. Sci. Soc. III., 356 13. Rhyolite, Hungary, v. Hauer, Verh. d. k. k. R. 1867, 118. 14. Quartz Porphyry, Upper Quinnesec Falls, Mich., G. H. Williams, Bull. 62, U. S. G. S. 120. 15. Quartz Porphyry, Waterville, N. H. Hawes, N. H. Geol. Surv. III. 178.

Comments on the Analyses.—The analyses illustrate the ranges of the various molecules. No. 1 is a very exceptional rock, alike in its high SiO_2 and CaO, and low Al_2O_3. The gradual increase of Al_2O_3 in all the others, with decrease of SiO_2, and in general the same relation as regards CaO are worthy of remark, as is the prevailingly low MgO. Sometimes K_2O, sometimes Na_2O, is in excess, and this brings out the reason why we spoke of orthoclase as the chief feldspar, not as the only one in the table, p. 19. The specific gravity is in general low.

Varieties.—Rhyolites proper are porphyritic rocks with phenocrysts of quartz, alkali-feldspar, usually orthoclase, of biotite, and less commonly hornblende and augite, in a ground-mass that is either glassy, or a finely crystalline aggregate of quartz and feldspar, or both. The name rhyolite was coined from the Greek verb to flow, on account of the frequent flow structure. It is the name mostly used in America and England, whereas liparite (from the Lipari Islands) and quartz-trachyte are employed in Europe. A variety with very little groundmass and an approximation to a granitoid texture is called nevadite, from the State of Nevada. In former years a distinction was made between the volcanic rocks of pre-Tertiary age and those of later date, and as against the later rhyolites the older were called quartz-porphyries, but the distinction has no serious foundations. At present some authors define quartz-porphyries as rocks corresponding to the rhyolites, but which have crystallized as intruded sheets, laccolites, sills and dikes. Nevertheless, while this distinction has some force, in any extensive collection of specimens no very notable difference can be detected in the hand specimens even by a very practiced observer. Rhyolites from the inner parts of thick surface flows, and from their branching dikes, can be found, especially when alteration has advanced somewhat, to match all quartz-porphyries, but as a general rule quartz-porphyries are denser and less cellular than rhyolites. The meaning of both words should be well understood on account of their presence in the literature. Certain *microscopic* structures due to the interpenetration of quartz and feldspar are also seen in the quartz porphyries (*i. e.*, intruded sheets), that are seldom met in surface flows, but these have no value in ordinary study. An old and very useful term is *felsite*, which has been applied especially to acidic lavas of ancient geological date, that lack phenocrysts, wholly or largely. Whether they correspond to rhyolites or to less acidic magmas, such as trachytes, is not always apparent without chemical analyses. Felsites are dense, usually green, red or gray rocks, which only indicate to the eye that they are very finely crystalline. They really consist almost entirely of minute quartz and feldspar crystals, practically a groundmass without phenocrysts, but it is not always apparent whether they represent original crystallizations from fusion, or devitrified obsidians (apobsidians) or recrystallized tuffs, all of which have been demonstrated in one place or another. Those certainly derived from rhyolites have been called aporhyolites.

Rhyolites high in soda are called soda-rhyolites, or pantellerites, (see analyses 1 and 2). Ancient rhyolites (quartz-porphyries, felsites) rich in soda have been called quartz-keratophyr (see analysis

12), the dist~~ribu~~inction being made because the feldspar present must be anorthoclase as against true orthoclase. As the true porphyritic texture graduates into the granitoid, we have intermediate rocks called granite porphyries, of which mention is made under granites.

Mineralogical composition.—The principal minerals present of recognizable size are quartz, in rounded or doubly terminated (*i. e.*, dihexagonal) pyramids with practically no prism faces; and feldspar, including orthoclase, less often anorthoclase, and a soda-lime plagioclase belonging in the series from albite to oligoclase. Biotite is much the commonest dark silicate, although hornblende, and less often augite, are occasional. It is important to appreciate that the dark silicates are vastly inferior in quantity to the light ones. As regards the groundmass, by the unaided eye, we can only determine that it is glassy (called also hyaline), or finely crystalline, that is, felsitic, or coarsely crystalline. Vesicular groundmasses are met in surface flows, not in intruded masses. Lithophysæ also occur in rhyolites as well as in volcanic glasses.

Relationships.—Rhyolites pass by insensible gradations into glasses on one side, trachytes on another, granites on a third and dacites on a fourth. Without the microscope rhyolites can only be identified with certainty by recognizing the quartz, and may then be confused with dacites. The striated feldspar of the latter is our chief means of distinction between the two.

Alteration.—Ordinary decay leads to the formation of clays and kaolin. In metamorphic alterations the rhyolites pass into very finely crystalline aggregates of quartz and feldspar, and then it is difficult to decide what minerals are original and what secondary, and whether the original rock was a massive one or a tuff. Shearing stresses develop schistose structures, and when decay is further superadded sericite schists may result that are extremely difficult geological problems.

Distribution.—Rhyolites are common in the Western States, being well known in the Black Hills; the Yellowstone Park; in Colorado, where Chalk Mountain, near Leadville, is a type locality for nevadite; in Nevada, both near Eureka and near the Comstock lode, and in California. The so-called quartz-porphyries have been also met in many Western districts, but are of especial importance at Leadville, where they are intimately associated with the ores. The ancient rhyolites (quartz-porphyries) have also an important development on Lake Superior. The greater part of the boulders in the Calumet copper conglomerate consist of them, and Lighthouse Point, near Marquette, furnishes an outcrop. Along the Atlantic Coast the pre-Cambrian rhyolites (felsites) are present in the same localities as those cited for volcanic glasses. Recent rhyolites are in vast quantity in Iceland. Many are known in Europe, but the enormous development in Hungary is especially worthy of note. The sheets of rhyolite on the Lipari Islands, between Naples and Sicily, suggested the name Liparite. In almost all volcanic districts they are liable to occur. In the Tyrolese Alps quartz-porphyries are of great extent, and in Scandinavia and in Cornwall, they form important dikes, familiar to all students of the subject.

RHYOLITE TUFFS.—These are the fragmental ejectamenta from explosive eruptions that often afford very extensive strata of rock. Although loose at the time of falling, they may become consolidated in the course of time, or before this occurs they may be sorted and redeposited in water so as to share the nature of a true sediment. Fragments of volcanic glass and of all the component crystals of rhyolite make them up, while larger fragments of rock and volcanic bombs are at times intermingled. Tuffs of ancient geological date become metamorphosed and recrystallized, so as to afford products not to be easily distinguished from compact felsites.

Rhyolite tuffs are abundant along the eastern foothills of the Front Range of Colorado, and are extensively quarried for a rather soft building stone.

THE TRACHYTES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	66.03	18.49	2.18	0.22	0.96	0.39	5.86	5.22	0.85	2.59
2.	65.07	16.13	5.17	. .	2.74	0.67	4.44	4.77	0.70	
3.	62.28	19.17	3.39	. .	1.44	. .	5.93	5.37	2.33	2.65
4.	62.17	18.58	2.15	1.05	1.57	0.73	3.88	7.56	1.70	
5	58.70	19.26	3.37	0.58	1.41	0.76	4.53	8.55	2.64	
6.	57.7	17.9	4.4	3.9	3.7	1.8	7.7	3.8	0.1	2.61

1. Trachyte, Game Ridge, Custer Co., Col., Cross, Proc. Col. Sci. Soc., 1887, 237. 2. Oligoclase-trachyte Drachenfels on Rhine, Rammelsberg, Z. d. d. g. G. XI., 440, 1859. 3. So-called Bostonite dike, Lake Champlain, J. F. Kemp, Bull. 107, U. S. G. S., 20. 4–5. Acmite-trachyte, Crazy Mountains, Mont., Wolff and Tarr, Bull. Mus. Comp. Zoöl. XVI., 232. 6. Trachyte, Arso Flow, Ischia near Naples. Abich, Isola d'Ischia, 38. Silica determinations on eleven trachytes from the Black Hills afforded J. H. Caswell values from 65.46 to 52.02.

Comments on the Analyses.—The decrease in silica and the increase in alumina and the alkalies as against the rhyolites is noteworthy. The alkalies in particular are high, with sometimes potash, sometimes soda, in excess. The latter marks the passage to the phonolites.

Varieties. Trachyte is a name derived from the Greek word for rough, and refers to the rough surfaces of those first studied. The name was of much wider application in earlier years than today and was used for both rhyolites and trachytes. If soda is high, the soda pyroxene acmite may form and give name to the rock as in analyses 4 and 5. Pantellerite is another name for those that are rich in soda and that have anorthoclase feldspar. The widely and loosely used name porphyry is applied to pre-Tertiary trachytes, and to intruded sheets and dikes. Bostonite has been employed for such dikes and to both dikes and sheets when rich in soda, the name keratophyre has been given. Many felsites also belong here, but for all these the remarks made under rhyolites apply. The distinctions are only of importance in close microscopical work and when the idea of the geological relations is involved in the definition, but both porphyry and felsite are useful current terms. Porphyry, it should be remarked, is employed in mining circles in the West, for almost every rock that occurs in dikes or sheets.

Mineralogical composition. The principal minerals of recognizable size are alkali-feldspar, chiefly orthoclase of the variety called sanidine, a little acidic plagioclase; more or less biotite, hornblende and pyroxene in this general order. The light-colored silicates are in notable excess over the dark ones. The groundmass is glassy or finely, or (rarely) coarsely crystalline.

Alteration. The alteration is practically the same as that described under rhyolites.

Relationships. With increase of soda, trachytes pass into phonolites, to which indeed they are closely related. With the development of granitoid texture they (including porphyries) pass into syenites. They are easily confused with some andesites unless the eye can detect the striated feldspar, but, as noted in the next paragraph, they are comparatively rare rocks.

Distribution.—True volcanic trachytes are extremely rare in this country, for many of the earlier cited localities, as, for instance, some of those in the Reports of the Fortieth Parallel Survey, have been shown to be andesites. Beautiful examples do, however, occur in the Black Hills, with superbly developed orthoclases. Others are known in Custer county, Col. (see Analysis 1), and in Montana (Analyses 4 and 5). The porphyries, strictly so-called, are not identified with certainty in very wide distribution, although, doubtless, many dikes in the West are properly described as such. In southeast Missouri, at Iron Mountain and Pilot Knob, they are very abundant. Many curious dikes occur around Lake Champlain, and among the pre-Cambrian volcanics of the Atlantic Coast they are not lacking. Abroad trachytes are more common, and along the Rhine,—where the peak of the Drachenfels is situated, which furnishes the commonest specimens for collections,—in the Auvergne, in Italy and in the Azores they are well known.

Trachyte Tuffs are not common in America, and offer only microscopic points of difference from those formed of rhyolitic material.

THE PHONOLITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss	Sp. Gr.
1.	61.08	18.71	1.91	0.63	1.58	0.08	4.63	8.68	2.21	2.582
2.	60.02	20.98	2.21	0.51	1.18	tr.	5.72	8.83	0.70	2.576
3.	59.46	23.00	3.52	. .	1.00	0.50	4.90	7.13	0.71	
4.	59.17	19.74	3.39	. .	0.92	0.15	6.45	8.88	1.18	2.566
5.	56.43	22.25	2.66	0.97	1.41	tr.	2.77	11.12	2.05	2.54
6.	49.18	20.65	. .	5.97	2.43	0.29	6.88	9.72	1.60	2.553
7.	45.18	23.31	6.11	. .	4.62	1.45	5.94	11.17	1.14	
8.	44.50	22.96	6.84	. .	8.65	1.65	4.83	6.70	2.06	

1. Devil's Tower, near Black Hills, Wyo. Pirsson, A. J. S., May, 1894, 344. 2. El Paso Co. Colo. Cross. Proc. Col. Sci. Soc., 1887, 169. 3. Island of Fernando de Noronha, Brazil, Gümbel Tscher, Mitt., 1880, II., 188. 4. Near Zittau, Saxony, v. Rath. Z. d. d. g. G, VIII. 297. 5. Wolf Rock, Cornwall, Eng., Phillips, Geol. Mag. VIII. 249. 6. Leucite-phonolite, near Rieden, Germany, Zirkel, Lehrbuch II., 465. 7. Eleolite-porphyry, Beemerville, N. J., J. F. Kemp, N. Y. Acad. Sci., XI., 69. 8. Eleolite-porphyry, Magnet Cove, Ark., J. F. Williams, Igneous Rocks of Ark., 261.

Comments on the Analyses.—It is at once apparent from the analyses that the range in silica, except in the last two, is much like that of the trachytes, but that the alumina goes higher, and that the alkalies are in extremely large amounts. No other rocks, except the corresponding granitoid types, reach these amounts in alkalies. The soda which is necessary for the formation of the nepheline is naturally in excess. The rare leucite-phonolites, as a general thing, are more basic and show comparatively high potash.

The last two analyses of intrusive or dike members are abnormally basic for phonolitic rocks.

Varieties.—The phonolites were named because in the thin plates in which they often break up they ring under the hammer. Nepheline or eleolite-porphyries have been described by a few observers, and certain ones in dikes have been named tinguaite from a Brazilian locality, but in their mineralogical composition they are practically phonolite, although at times exceptionally basic. Leucitophyr is applied to phonolites with both nepheline and leucite, while leucite phonolite is used for those that have no nepheline.

Mineralogical Composition.—The principal minerals are orthoclase, variety sanidine, and nepheline or leucite, or both. The nepheline is seldom visible to the eye, and indeed it is practically necessary, in order to assure oneself of the rock to warm up a little of it powdered, in dilute acid, and evaporate for gelatinous silica. Nepheline gelatinizes so readily that it is easily detected. Nosean and hauyne are frequent in phonolites. The commonest of the dark silicates are the soda-pyroxenes, acmite and ægirine. Hornblende is known, but biotite is seldom seen. The rocks have usually a compact gray or green groundmass in which are visible, shining sanidines, seldom nepheline or leucite, and rarely dark rods of pyroxene, because the pyroxene, though always present, is usually microscopic. In connection with pre-Tertiary rocks the name eleolite is sometimes used for nepheline.

Relationships.—The phonolites are closely related to the trachytes as already stated. They have also intimate connections with certain rare, basaltic rocks to be referred to later that contain nepheline and leucite.

Alterations.—The nepheline changes quite readily to natrolite and perhaps analcite, while leucite yields analcite. Metamorphic processes are yet to be studied.

Distribution.—The true volcanic phonolites are only known as yet in two localities in this country, the Black Hills, where they form dikes, sheets and isolated buttes (Devil's Tower), and the Cripple Creek mining district of Colorado, where the comparatively few dikes known have proved of great importance as associates of the ores. Nepheline- or eleolite-porphyries (tinguaites) are recorded as exceedingly rare rocks near Magnet Cove, Ark., and Beemerville, N. J., associated with nepheline-syenite. Phonolites are much more abundant abroad, being well known in many parts of

Germany. The varieties with leucite are especially familiar from the vicinity of Rieden, in the extinct volcanic district of the Eifel. A peculiar leucite rock, with abundant scales of biotite, gives the name to the Leucite Hills, two or three miles north of Point of Rocks, Wyo. Leucite tinguaites occur near Magnet Cove, Ark., in the Highwood Mountains, Mont., and near Rio Janeiro, Brazil.

Tuffs are known abroad but not in this country, and exhibit few features calling for special mention.

THE GRANITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	73.76	13.43	1.16		1.42	0.75	5.22	4.01	0.42	2.63
2.	73.70	14.44	0.43	1.49	1.08	tr.	4.43	4.20	0.40	2.69
3.	73.05	14.53	2.96	. .	2.06	tr.	5.39	1.73	0.29	
4.	72.73	16.95		. .	1.05	tr.	8.15	0.90	0.22	
5.	72.26	15.59	1.16	2.18	1.13	0.06	5.58	3.85	0.47	2.65
6.	71.78	14.75	. .	1.94	2.36	0.71	4.89	3.12	0.52	
7.	71.64	15.66	2.34	. .	2.70	tr.	5.6	1.58	0.48	
8.	69.46	17.50	2.30	. .	2.57	0.30	4.07	2.93	0.82	2.687
9.	69.28	17.44	2.30	. .	2.30	0.27	2.76	3.64	. .	
10.	68.68	16.28	0.66	2.55	2.24	0.81	4.07	2.88	0.85	
11.	66.84	18.32	2.27	0.20	3.31	0.81	2.80	5.14	0.46	
12.	66.68	14.93	1.58	3.23	4.89	2.19	2.05	2.65	1.25	
13.	66.40	17.13	. .	3.77	4.05	0.94	2.08	4.49	1.03	

1. Biotite granite, Green's Landing, Me., E. F. Hicks. Privately communicated. 2. Granitite, Peterhead, Scotland, Phillips, Q. J. G. S., XXXVI., 1880, 13. 3. Red Granitite, Westerly, R. I., F. W. Love, for J. F. K., unpublished. 4. Red Granite, Stony Point, Conn., L. P. Kinnicut, Anal., unpublished. 5. Albany granite, N. H Hornblende granite, G. W. Hawes, A. J. S., iii., XXI., 25. 6. Hornblende granite with biotite, Cottonwood Cañon, Utah, T. M. Drown, 40th Parallel Surv., I., 110. 7. Gray granitite, Westerly. R. I., see No. 3. 8. Typical granite, Chester, Mass., L. M. Dennis, for J. F. K., N. Y. Acad. Sci., XI., 129. 9. Biotite granite, Raleigh, N. C., G. P. Merrill, Stones for building and decoration, 418. 10. Biotite granite with hornblende, Wood Cone, Eureka Dist., Nev., A. D. Hague, Mono., XX., U. S. G. S., 228. 11. Augite-soda granite, Kekequabic Lake, Minn., U. S. Grant, Amer. Geol., June, 1893, 385. 12. Granitite, Rowlandville, Md., Jour. Cin. Soc. Nat. Hist., 1894, p. 32. 13. Biotite granite with hornblende, El Capitan, Yosemite, see No. 6.

Comments on the Analyses.—These analyses illustrate the general range of SiO_2, but granites are known outside of both limits. As SiO_2 decreases the bases increase, and soda tends to exceed potash, marking the passage to the diorites. Those high in Na_2O, like No. 11, are often called soda-granites. They are analogous to the keratophyres, soda-rhyolites and pantellerites, earlier referred to.

The whole table is a close parallel to that of the rhyolites. The analyses are selected, so far as possible, to represent prominent building stones.

Mineralogical Composition and Varieties.—Granites are, par excellence, granitoid rocks consisting of orthoclase, sometimes microcline, some acid plagioclase, quartz, and in the typical variety both biotite and muscovite. Magnetite, apatite and zircon are always present, though small, and garnet is not at all unusual. Biotite is much the commoner of the micas, and when it is present alone the rock is sometimes called granitite. Granites with muscovite alone are especially found in the form of dikes. They are called aplite. Hornblende is also frequently met, either with biotite or by itself, giving then hornblende-granite. In former years this aggregate was called syenite, but the modern usage is different. Augite in granites is uncommon, and marks a passage to the gabbros. All forms of dark silicates and mica may fail, and then we have the so-called binary granites. Some Missouri granites are of this character.

Especially in regions of granite intrusions and of extensive metamorphism, veins or dikes—it is an open question which is the more correct term—are met formed of very coarsely crystalline aggregates of the same minerals that constitute granite. These are called pegmatite and in them is the home of graphic granite, the curious intergrowth of quartz and feldspar, such that a cross fracture of the blades of quartz suggests cuneiform characters. Garnet, tourmaline, beryl and minerals involving the rare earths, are often found in pegmatites, and they supply the feldspar and mica of commerce. The outcrops may be two hundred feet broad or more, and again the same aggregates are found as small lenses or "Augen" in metamorphic rocks. In regard to the larger veins or dikes it seems improbable that true igneous fusion could have afforded such coarsely crystalline aggregates, and so we are forced to assume such abundance of steam and other vapors, *i. e.*, mineralizers, as to almost, if not quite, imply solution.

Undoubted dikes of the composition of granite are also known, that have no such unusual size of minerals, but that tend to develop a porphyritic texture from the presence of feldspars larger than the general run of the component minerals. These are called granite-porphyries, and they pass by insensible gradations, through finer and finer groundmasses, into typical quartz-porphyries. The phenocrysts of granite-porphyries may also fail and the groundmass may become finer and finer, passing through a stage called micro-granite into the felsites.

The outer portions of granite masses are often subjected to the action of escaping vapors, containing boracic and hydrofluoric acids (fumarole action). These develop tourmaline in quantity and often fluorite, and in rare instances cassiterite. In a famous case near Luxullian, in Cornwall, the feldspar has become changed to an aggregate of tourmaline needles and quartz, and the rock is called luxullianite. Tourmaline granite is, however, also known in which tourmaline plays the role of mica or hornblende, as at Predazzo, in the Tyrol. Fumarole action may change the borders of granites to a mass of quartz and a lithia mica, affording the rock that is called greisen and that is a familiar gangue for tin ores.

Granites are commonly gray, bluish or reddish in color. The feldspar is mainly responsible for this, as quartz is colorless and transparent and biotite and hornblende are not specially abundant; but unusual richness in the last named silicates tends to darken the shade. These latter are very frequently segregated into the black bunches that are noticeable in many building stones. They may be spheroidal in their alignment, affording so-called orbicular granite.

Relationships.—The passage of granites, through granite-porphyries and micro-granites, into quartz-porphyries and felsites, has been remarked. Sometimes along the border of an intrusion, this can be traced inch by inch to a place where the porphyritic texture is due to a quick chill. Mt. Willard, in the Craw[illegible] Notch of the White Mountains is a classic locality of this ph[illegible]enon. It was described in 1881 by Geo. W. Hawes (see analy[illegible], and will be referred to again under the rocks of contact metamorphism. The close relationship of the granitoid rhyolites or nevadites with granite need only be referred to. As quartz decreases, syenites result by insensible gradations, and as hornblende or biotite and plagioclase increase, the same passage is made to diorites. Intermediate varieties, which are very common, are often called granite-diorites or grano-diorites. Transitional passages to gabbro, from increase of augite and plagioclase, are also well recognized.

Geological Occurrence.—Granites in their most typical development constitute great irregular masses that have solidified at depths; such are called bathylites, and it is generally believed that before consolidating they have often fused their way upward by melting into themselves overlying rock. Granites also appear as irregular or rounded outcrops in the midst of other rocks (bosses or knobs) and as dikes. There is no reason why granites should not form at all geological ages, but those open to our observation are mostly Archean and Paleozoic because, being deep-seated rocks, only the older ones have been exposed by erosion. The relations of pegmatites to veins have been earlier set forth. Granites tend to break apart by jointing planes in rectangular blocks, a property that much facilitates their quarrying. They also have lines of weakness admitting of their further division into smaller masses. The development of these is more or less characteristic of each particular locality.

Uses.—Granites are much more extensively employed for structural purposes than any other igneous rock, and indeed in the trade any crystalline rock consisting of silicates is called granite. They are in general the strongest of the common building stones. Crushing resistances range from 10,000 to 25,000 pounds per square inch in a 2-inch cube. The important points are homogeneity of texture, good, rectangular cleavages in the quarry, adaptability to tool treatment, and pleasing color.

Alteration, Metamorphism.—In ordinary decay granites suffer first by the oxidation of the protoxide of iron in the ferromagnesian silicates (biotite, hornblende), and the formation of chlorite and other secondary minerals. The feldspars also kaolinize, and the rock thus becomes hydrated. Pyrite, if present, is an active agent in deca[illegible] Yet the chemical changes involved, except hydration, seem [illegible] comparatively slight even in the change from granite to so[illegible]. P. Merrill gives the following analyses of unaltered and altered biotite granite from the vicinity of Washington, D. C. (Bull. Geol. Soc. Amer. VI., 323).

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Ignition.
1.	69.33	14.33	. .	3.60	3.21	2.44	2.67	2.70	1.22
2.	66.82	15.62	1.88	1.69	3.13	2.76	2.04	2.58	3.27
3.	65.69	15.23	4.39		2.63	2.64	2.00	2.12	4.70

No. 1 is fresh and undecomposed rock; No. 2, decomposed but still moderately firm rock; No. 3, soil. It is evident at once that there has been considerable hydration, and that a notable decrease in the alkalies has occurred, each being affected about equally in the end, although K_2O yields first; MgO has relatively increased; CaO has suffered loss; the FeO is all oxidized, the Al_2O_3 has relatively increased and the SiO_2 decreased. While appreciating these chemical changes, Dr. Merrill still emphasizes the much greater importance of the physical alteration and attributes this to swelling from hydration. Other interesting data are given in the citation. Similar sets of parallel analyses have been made abroad with analogous results in the case of the chemical rearrangements.

Under dynamic stress granites are more or less crushed and have their minerals drawn out into laminations from shearing strains so that they readily assume gneissoid structures. Beyond question many gneisses have resulted in this way, and in the geology of some districts, as, for instance, the Front Range of Colorado, we employ the term granite-gneiss. The structures were, doubtless, induced while the granite was deeply buried and subjected to pressure while closely confined, so that the yielding came in a gradual flow.

Distribution.—Granites are abundant along the Atlantic coast, and are near tidewater from Canada to Virginia. Further south they lie back of the Coastal Plain. They are chiefly biotite granite and are extensively quarried. A famous hornblende granite is obtained at Quincy, Mass., that was formerly called syenite. In the old crystalline areas of Michigan, Wisconsin and Minnesota they are common. Missouri has many in the region of the porphyries, already cited. In the West, the Black Hills, the Rocky Mountains, the Wasatch and the Sierras are abundantly supplied. They are equally common in Europe and elsewhere the world over.

THE SYENITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss	Sp. Gr.
1.	60.03	20.76	4.01	0.75	2.62	0.80	5.48	5.96	0.59	
2.	59.83	16.85	. .	7.01	4.43	2.61	6.57	2.44	1.29	2.73
3.	59.78	16.86	3.08	3.72	2.96	0.69	5.01	5.39	1.58	2.689
4.	59.37	17.92	6.77	2.02	4.16	1.83	6.68	1.24	0.38	2.71
5.	56.45	20.08	1.31	4.39	2.14	0.63	7.13	5.61	1.77	
6.	46.11	14.75	2.20	4.51	7.82	5.73	3.84	1.29	1.59	2.904
7.	46.73	10.05	3.53	8.20	13.22	9.68	3.76	1.81	1.24	

1. Fourche Mtn., near Little Rock, Ark., J. F. Williams; Igneous Rocks of Ark., 88. 2. Plauen, near Dresden, F. Zirkel, Pogg. Ann., CXXII., 622. 3. Custer Co., Colo. Cross, Proc. Colo. Sci. Soc., 1887, 240. 4. Biella, Piedmont,Cossa., Turin Acad. ii., XVIII., 28. 5. Sodalite-Syenite Highwood Mtns., Mont. W. Lindgren, A. J. S., Apr., 1893, 296. 6. Minette, Rhode Island, badly decomposed, contained CO_2 7.32,

Pirsson, A. J. S., Nov., 93, 375. 7. Shonkinite, Highwood Mtns., Mont., Pirsson, Bull. Geol. Soc. Amer. VI. 414.

Comments on the Analyses. The syenites mark a decrease in SiO_2 from the granites and a general increase in all the bases The high percentage of alkalies is especially worthy of remark, and the notably large amounts of soda, showing the passage to the nepheline syenites. The parallelism with the trachytes is close. The last two analyses exhibit excessively basic extremes, whose theoretical significance is commented on in the next paragraph.

Mineralogical Composition, Varieties.—The name syenite was suggested by Syene, now Assuan, an Egyptian locality where a hornblende granite was formerly obtained for obelisks, and if its local significance were perpetuated, syenite as formerly should be applied to this rock. But Werner used it in the last century for the well-known typical rock from the Plauenschen Grund (see Analysis 2), near Dresden, that contains almost no quartz, and of recent years this has been its correct use. Typical syenites have orthoclase and hornblende; those with biotite are called mica-syenites. Some plagioclase is always present and magnetite, apatite and zircon are invariable. Mica syenites in dikes, basic and of dark color have been called minette. Orthoclase and augite afford augite-syenite. An excessively basic one (Analysis 7), from the Highwood mountains, Mont., has recently been described by Pirsson under the name Shonkinite. It is of great theoretical importance, as it shows that orthoclase is not limited to acidic rocks, but may be the prevailing feldspar in very basic ones. Still more recently J. P. Iddings has noted others of similar character from the region of the Yellowstone Park. (Jour. of Geology, December, 1895, 935.) Basic nepheline-syenites have been earlier known. Still the table on page 55 expresses the general truth, the exceptions being excessively rare rocks so far as yet known. Syenites are themselves rare rocks. With high soda, the mineral sodallite develops and yields sodalite syenites which are passage forms to nepheline syenites.

Relationships.—Syenites are most closely allied with nepheline-syenites, into which with increase of soda they readily pass. They also with increasing plagioclase shade into diorites and the augite-syenites are closely akin to gabbros.

Geological Occurrence.—Syenites form irregular masses and dikes, precisely as do granites.

Alteration.—There is little to be said that was not covered under granite. The rarity of syenite makes it a much less serious factor. In metamorphism they pass into gneisses.

Distribution—Syenites occur in the great igneous complex of the White Mountains. They form large knobs and dikes near Little Rock, Ark., and a dike is known in Custer county, Colo. The only American minette yet discovered, is a dike on Conanicut Island, R. I., described by Pirsson (see Analysis 7). Abroad, syenites are better known. The Plauenscher Grund, near Dresden, Biella in the Piedmont, and the vicinity of Christiania, Norway, are the best known. Minettes are especially famous in connection with the mining district about Freiberg, Saxony, and in the Vosges mountains.

THE NEPHELINE SYENITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	60.39	22.51	0.42	2.26	0.32	0-13	4.77	8.44	0.57	
2.	59.70	18.85	4.85	. .	1.34	0.68	5.97	6.29	1.88	
3.	59.01	18.18	1.63	3.65	2.40	1.05	5.34	7.03	0.50	
4.	56.30	24.14	1.99	. .	0.69	0.13	6.79	9.28	1.58	
5.	54.20	21.74	0.46	2.36	1.95	0.52	6.97	8.69		
6.	52.75	22.55	3.65	. .	1.85	0.15	7.05	8.10	3.60	
7.	51.90	22.54	4.03	3.15	3.11	1.97	4.72	8.18	0.22	
8.	50.96	19.67	7.76	. .	4.38	0.36	6.77	7.67	1.38	
9.	50.36	19.34	6.94	. .	3.43	. .	7.17	7.64	3.51	
10.	41.37	16.25	16.93	. .	12.35	4.57	3.98	4.18	0.45	

1. So-called Nepheline-syenite, or Litchfieldite, Litchfield, Me., W. S. Bayley, G. S. A., III., 241. 2. Nepheline-syenite, Fourche Mountains, Ark., J. F. Williams, Igneous Rocks of Ark., 88. 3. Nepheline-syenite, Red Mountains, N. H., W. S. Bayley, G. S. A., III., 250. 4. Ditroite, Hungary, Fellner, Neues, Jahrb., 1868, 83. 5. Foyaite, Portugal, Jannasch. Neues Jahrb., II., 11. 6. Nepheline syenite, Sao Paulo, Brazil, Machado. Tsch. Mitt., IX., 1888, 334. 7. Laurdalite, variety of Nepheline-syenite. Lund, Norway, Brögger, Syenit-pegmatit-gäuge, 33. 8. Leucite-syenite, Arkansas, J. F. Williams. Igneous Rocks of Ark., 276. 9. Nepheline-syenite, Beemerville, N. J., F. W. Love for J. F. K., N. Y. Acad. Sci., XI., 66. 10. Basic Nepheline-syenite, Beemerville, N. J., J. F. Knmp, N. Y. Acad. Sci., XI., 86.

Comments on the Analyses.—A considerable range is shown in the SiO_2, some analyses going below the usual percentages for syenites and the last analysis being abnormal. In general the amounts of alkalies are extremely high, with Na_2O in excess, in which respect the phonolites are paralleled.

Mineralogical Composition and Varieties.—The minerals of nepheline syenite are in general the same as those of syenite proper, with the addition of nepheline, often sodalite, and several characteristic ones into which the rare earths often enter as bases. Zircon is widespread and often large enough to afford fine crystals. For this reason the rocks were named zircon-syenite many years ago. The nepheline is often called eleolite (or elæolite), from the former custom of speaking of this mineral in pre-Tertiary rocks as elæolite and in later ones as nepheline, just as we have had orthoclase and sanidine, but the custom is gradually falling into disuse. Attempts have been made to give different names according to the dark silicate; for instance, those with hornblende were called foyaite, from Foya, a Portuguese locality; those with biotite, miascite from Miask, in the Urals. But both these minerals so often appear together or with pyroxene that the practice is not generally observed. Ditroite is a variety rich in blue sodalite. The Litchfield, Me., rock has been shown by Bayley to have as its feldspar almost exclusively albite, and he, therefore, has called it litchfieldite. The texture of nepheline-syenites varies very much. At times it is very coarsely granitoid, and again it is what is called trachytic, *i. e.*, with little rods of feldspar, more or less in flow lines, like a trachyte and marking a passage to the phonolites. Types have been based on these characters. Where at all finely crystalline, the determination of nepheline-syenites, as against true syenites, is a matter for the microscope. Nepheline-syenites are comparatively rare rocks. Corresponding rocks with leucite are as yet only known from Arkansas and Montana.

Relationships.—As already remarked, the nepheline-syenites are closely related to the true syenites, and to the phonolites. With certain basic plagioclase rocks with nepheline, called theralites, they are also of near kinship.

Geological Occurrence, Alteration.—The nepheline-syenites are specially prone to appear as dikes, often on a very large scale. Their alteration affords no special features, as distinguished from the syenites or granites, except as regards the secondary minerals from the nepheline. Natrolite, muscovite and kaolin are all known in this relation and the last two have been called liebenerite and gieseckite. Cancrinite also results from the alteration of nepheline. The rarity of the nepheline-syenites has prevented their playing an important role among metamorphosed rocks.

Distribution.—Nepheline-syenites are known in this country at

Montreal and Dungannon, Ont.; Litchfield, Me.; Red Hill, N. H.; Salem, Mass.; Beemerville, N. J., where a superb dike is exposed; and near Little Rock, Ark., where the area is extensive. Very interesting ones occur near Rio Janeiro, and in the State of Sao Paulo, Brazil. Abroad the Portuguese locality, in the Monchique Mountains; the one at Ditro, in Hungary, and the wonderful dikes near Christiania, in Norway, so prolific in rare minerals, are of especial interest.

CHAPTER IV.

THE IGNEOUS ROCKS, CONTINUED. THE DACITES, THE ANDESITES AND THE ROCKS OF THE BASALT GROUP.

THE DACITES AND ANDESITES.

THE DACITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	69.96	15.79	2.50	. .	1.73	0.64	3.80	4.12	1.53	
2.	69.36	16.23	0.88	1.53	3.17	1.34	4.06	3.02	0.45	
3.	67.49	16.18	1.30	1.22	2.68	1.34	4.37	2.40	2.69	
4.	67.2	17.0	3.5	1.2	4.5	1.5	3.7	1.6	0.9	
5.	67.03	16.27	. .	3.97	3.42	1.19	2.71	3.50	1.56	
6.	66.03	14.57	2.57	1.19	3.38	1.89	3.71	2.70	2.07	
7.	63.36	16.35	2.12	3.05	4.79	3.28	3.58	2.92	0.99	

THE ANDESITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
8.	67.83	15.02	. .	5.16	3.07	0.29	2.40	3.20	1.11	
9.	65.50	14.94	1.72	2.27	2.33	2.97	5.46	2.76	1.37	
10.	63.49	18.40	2.44	1.09	2.30	.66	5.70	4.62	1.04	
11.	62.94	18.14	. .	3.82	6.28	3.06	3.83	1.22	0.60	
12.	61.62	16.86	. .	6.61	6.57	2.07	3.93	1.66		
13.	61.58	16.34	. .	6.42	5.13	2.85	2.69	3.65	0.64	
14.	59.48	16.37	3.21	3.17	4.88	3.29	3.30	2.81	2.02	
15.	56.19	16.12	4.92	4.43	6.99	4.60	2.96	2.37	1.03	
16.	56.91	18.18	4.65	3.61	7.11	3.49	4.02	1.61	0.36	

1. McClelland Peak, near Comstock Lode, Nev., F. A. Gooch., Bull. 17, U. S. G. S., 33. 2. Lassen's Peak, California, Hague and Iddings, A. J. S., Sept., 1883, 232. 3. Sepulchre Mountain, Yellowstone Park, J. P. Iddings, Phil. Soc. Wash., XI., 210. 4. Nagy-Sebes, Hungary, Doelter Tscher. Min. Petr. Mitt., 1873, 93. 5. Eureka Dist., Nev. A. Hague Mono., XX., U. S. G. S., 264. 6-7. Colombia, S. America. From Küch's Petrographie of Colombian Volcanoes, quoted in Jour. Geol., I., 171. 8. Hb.-mica-andesite, Eureka Dist., Nev., Mono., XX., U. S. G. S., 264. 9. Hb.-mica-andesite, Sepulchre Mountain, Yellowstone Park, J. P. Iddings, Phil. Soc. Wash., XI., 210. Compare No. 3. 10. Mica-andesite, Rosita Hills, Colo., W. Cross, Colo. Sci. Soc., 1887, 250. 11. Lassen's Peak, Calif., Hague and Iddings, A. J. S., Sept., 1883, 225. 12. Mt. Rainier. See last reference. 13. Pyroxene-andesite, Eureka Dist., Nev., Mono., XX.

U. S. G. S., 264. Compare No. 5. 14. Hypersthene-andesite, near Red Bluff, Mont., G. P. Merrill, Proc. U. S. Nat'l Museum, XVII., 651. 15. Hypersthene-andesite, Buffalo Peaks, Colo., W. Cross, Bull I., U. S. G. S., 26. 16. Colombia, S. America. See Nos. 6 and 7.

Comments on the Analyses. It appears at once from the analyses, that the dacites are high in silica, in which they equal the lower ranges of rhyolites. As compared with the latter, soda is prevailingly in excess of potash, and as a rule the other bases run higher. The andesites lap over the lower limits of the dacites and have much the same range in silica as the trachytes. All the bases reach notable percentages, but the alkalies recede as the others increase.

Mineralogical Composition, Varieties. The name dacite is derived from the old Roman province of Dacia, now a part of modern Hungary The name andesite was suggested by the abundance of these lavas in the Andes Mtns. Quartz occurs usually in abundant crystals in the dacites, causing them to closely resemble the rhyolites. The distinction, when it can be made, and this is not always without the microscope, depends on the prevalence of striated feldspars. The prevailing dark silicate is biotite, as is usually the case with an acidic rock. Hornblende and augite are rarer. Magnetite and the small accessory minerals, apatite, zircon, etc., are generally present. In the acidic andesites, biotite is also commonest; hornblende and then pyroxene favor those of decreasing silica. Andesites with biotite are usually called mica-andesites. Andesite when used alone implies hornblende-andesite. Prevailing augite is indicated by the name augite-andesite. If magnesia is in considerable amount hypersthene may result and afford hypersthene-andesite, a frequent rock in the West, but for all one can usually say from ordinary examination, the rocks may be augite-andesite, or even hornblende-andesite. Andesites strongly resemble trachytes, but it is to be appreciated that trachytes are comparatively rare rocks, while andesites are among our commonest lavas, and along the west coast of North and South America are the prevailing volcanic rock. The dark silicates are also increasingly abundant in the andesites. They pass insensibly into diorites, by the development of granitoid texture. The older andesitic lavas have been called porphyrites, on the analogy of porphyry, and then mica, or hornblende or augite is prefixed. Others use porphyrite for intruded sheets and dikes; and others still for varieties, with a groundmass of medium coarseness, restricting thus andesite to the finely crystalline or glassy varieties of groundmass and diorite to the coarse, granitoid rocks. These distinctions belong, however, to the refinements of the subject.

On analogy with the name trachyte, which was formerly applied in the field to all these more or less rough and cellular lavas, but which is now, by universal consent, restricted to the orthoclase rocks, G. F. Becker has suggested that " asperite" be used for those with plagioclase, basing it on the Latin word for rough. With general acceptance it ought to prove a very useful term, because the observer is often in doubt whether a rock is dacite or andesite, and if the latter, to which group it belongs. Propylite is a name still more or less current in the West. It was created for a series of rather coarsely crystalline or granitoid andesites, that are of pre-Tertiary age, and that often have the dark silicates altered to secondary minerals. The name means " before the gates," and the significance was that coming just before the geological time of the true volcanics, yet resembling them, they deserved this distinction. It is now obsolete and reasons for its special existence were long ago exploded, but having been employed on the Comstock lode, it has passed into western usage. There is no special and necessary geological age for any igneous rock.

Alteration, Metamorphism.—The andesites in decay afford kaolinized material and mixtures of this with chloritic products that are very difficult to identify. Thus the now famous andesitic breccia at Cripple Creek, Colo., can rarely be shown to the eye to be other than a white, kaolinized mass, and decomposed outcrops of massive flows are no less unsatisfactory. Where metamorphic processes affect older flows, felsitic and silicified forms, result similar to those mentioned under rhyolites. The tracing of the history of the rock is then a matter for the microscope and chemical analysis, when indeed it can be done.

Tuffs.—Andesitic tuffs and breccias (*i. e.*, aggregates of angular, volcanic ejectments coarser than tuffs) are rather common in the western volcanic districts. With ordinary observation they can only be identified by finding fragments large and fresh enough to indicate the original. Such have proved of great economic importance at Cripple Creek, Colorado.

Distribution.—Andesites are very wide-spread in the West. The vast laccolites that form many of the peaks in Colorado are intruded andesites (porphyrites) of a rather acidic type, frequently with some orthoclase. In the Yellowstone Park they are important. In Nevada, as at Eureka and the Comstock lode, they have proved of great geological interest, and especially near the latter, with its many miles of drifts, shafts and tunnels, very important data for the study of rock masses have been afforded. The old cones along the Pacific, Mt. Hood, Mt. Shasta, Mt. Rainier and others are chiefly andesite. The products of Mexican and South American volcanoes are also of this type, and indeed along the whole Pacific border the recent lavas have many features in common. Abroad andesites are seldom lacking in great volcanic districts.

THE BASALTS, INCLUDING DIABASE.

Basalts.	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	Na_2O.	K_2O.	Loss.	Sp. Gr.
1.	57.25	16.45	1 67	1.77	7.65	6.74	3.00	1.57	0.45	
2.	53.81	13.48	3.02	7.39	10.34	6.46	3.23	0.64	0.57	2.75
3.	53.62	22.09	4.21	. .	6.02	6.24	3.16	0.57	5.03	
4.	52.27	17.68	2.51	5.00	8.39	6.05	4.19	1.58	0.82	
5.	51.58	11.92	2.96	13.05	8.52	4.09	0.95	0.34	1.52	2.989
6.	50.38	19.83	6.05	2.00	10.03	5.36	2.15	1.76	1.37	
7.	49.45	17.58	3.41	3.41	7.20	4.05	5.83	1.57	4.34	
8.	49.04	18.11	2.71	7.70	7.11	4.72	4.22	2.11	1.29	2.738
9.	48.40	17.95	2.28	8.85	10.05	6.99	2.86	1.03	0.34	2.8
10.	47.54	19.52	4.24	6.95	11.70	6.66	3.09	0.16		2.981
11.	46.43	17.10	11.16	. .	10.38	9.78	2.50	. .	2.65	
Diabases.										
12.	54.52	19.10	2.83	5.89	7.25	3.92	3.73	2.30.	0.59	2.7
13.	53.13	13.74	1.08	9.10	9.47	8.58	2.30	1.03	0.90	2.96
14.	49.28	15.92	1.91	10.20	7.44	5.99	3.40	0.72	3.90	2.86
15.	48.75	17.17	0.41	13.62	8.82	3.37	1.63	2.40	. .	2.985
16.	46.28	12.96	4.67	6.06	10.12	8.71	3.75		3.34	2.921
17.	45.46	19.94	15.36	. .	8.32	2.95	2.12	3.21	2.30	2.945
Limburgite.										
18.	46.90	10.17	1.22	5.17	6.20	20.98	1.16	2.04	5.42	2.86
19.	40.22	14.41	17.42	2.36	11.53	7.29	3.94	1.90	1.10	2.89
Nepheline-basalt.										
20.	38.35	9.18	20.32	. .	11.76	13.78	2.77	2.02	1.20	3.223

1. Basalt with quartz, Cinder Cone, Calif., J. S. Diller, A. J. S., Jan., 1887, p. 49, Anal. Hillebrand. 2. Kilauea, Sandwich Is.; Cohen., Neues Jahrb. 1880, II., 41. 3. Iceland, Schirlitz. Tsch. Mitt., 1882, 440. 4. Rio Grande Canon, N. M., J. P. Iddings, A. J. S., Sept., 1888, 220, Anal. Eakins. 5. Dalles, Oregon, Lemberg, Z. d. d. g. G. XXXV. 116. 6. Richmond Mtn., Eureka Dist., Nev., A. Hague, Mono, XX., U. S. G. S., 264, Analyst Whitfield. 7. Point Bonita, Calif., F. L. Ransome, Bull. Geol. Dept., Univ. Calif., I., 106. 8. Buffalo Peaks, North Park, Colo., Woodward, 40th Parallel

Surv., II., 126. 9. Shoshone Mesa., Nev., Woodward, 40th Par. Surv., II., 617. 10. Cascade Mts., Oregon, Jannasch, Tsch. Mitth., 1881, 102. 11. Glassy basalt, Edgecombe Island, near Sitka, Alaska, Lemberg, Z. d. d. g. G., XXXV., 570. 12. Diabase Hills, Nev., Woodward, 40th Parallel Surv., I., Table opposite p. 676. 13. Penn. R. R. cut, Jersey City, N. J., G. W. Hawes, A. J. S., iii., IX., 186. 14. Lake Saltonstall, Conn., Ibid. 15. Dike near Boston, Mass., W. H. Hobbs, Bull. Mus. Comp. Zool., XVI., 1. 16. Point Bonita, Calif., F. L. Ransome, Bull. Geol. Dept., Univ. Calif., I., 106. 17. Dike at Palmer Hill, Ausable Forks, N. Y., J. F. Kemp, Bull., 107., U. S. G. S. 26. 18. Limburgite, Bozeman, Mont., G. P. Merrill, Proc., U. S. Natl. Mus., XVII., 640, Anal. Chatard. 19. Limburgite, Palma., L. Van Werveke, Neues Jahrb. 1879, 485. 20. Nepheline-basalt, Pilot Knob., near Austin, Texas, J. F. Kemp, Amer. Geol., Nov., 1890, 293.

Comments.—The first analysis is very like the more basic andesites, except in its high percentage of MgO. It is of a curious and exceptional basalt with quartz phenocrysts, regarding which, mention is made later. In general, the others are notably high in the oxides of iron, in CaO and MgO. The specific gravity is also high. The analyses of diabases differ in no essential from those of true basalts. No. 13 is of especial interest, as it is the one usually quoted as the representative of our Triassic diabases. The last three are representatives of the unusual varieties, later mentioned, that are of rare occurrence in the United States, but that represent the limiting percentages of SiO_2 in rocks mostly composed of silicates.

Mineralogical Composition. Varieties.—The name basalt is a a very ancient term and has been explained in several ways. Many regard it as a corruption of basanites which was used by Pliny, but for what rock is uncertain. The Greek word for the black-touchstone or Lydian stone used by the ancient jewellers is similar to this last form. Others refer it to Basan or Bashan, the kingdom of Og, as mentioned in the Old Testament, Deuteronomy III., 1. Again an Ethiopian word "basal" used by Pliny for an iron-bearing rock, has been suggested. Agricola in the sixteenth century gave it its present signification.

It stands for a very large and important group, which has many mineralogical varieties, but which can seldom be subdivided without exact microscopical study. The name basalt, therefore, embraces them all when megascopically considered. They are all heavy, black, gray or brown rocks, usually porphyritic, but at times lacking all phenocrysts and merely a closely crystalline dark rock. Plagioclase, augite, olivine and magnetite are the chief minerals present, and the groundmass is usually a finely crystalline aggregate of these and of some dark glass. At the acidic extreme of basalts are certain dark rocks, with abundant augite, that yet lack olivine. Though closely related to the augite-andesites, they are sometimes called *olivine-free basalts.* The typical basalt has, however, olivine, and often exhibits this mineral in large rounded masses. Coarsely crystalline basalts are called *dolerites*, a very common and useful field term. Typical dolerites are porphyritic but shade into granitoid varieties. An old group of rocks and one whose name often puzzles beginners as regards its special significance is called diabase. The diabases are generally entirely crystalline and apparently of a granitoid texture. The feldspars are, however, in long and relatively narrow crystals, as contrasted with the broader ones of typical granitoid rocks. In the interstices of these lath-shaped feldspars are found the dark silicates and magnetite. The texture is called *ophitic* and is more especially of microscopic importance. There is, therefore, ground for difference of opinion as to whether the diabases should be placed with the granitoid or with the porphyritic rocks, but as they are always in sheets or dikes, which shade into porphyritic forms on the contacts, and which are really volcanic in their nature, they are put here as essentially basalts at the extreme of the group toward the granitoid division. In former times the name was only used for pre-Tertiary rocks; but as often stated, the time distinction has been long since exploded. There are both diabases and olivine-diabases, but really except in connection with microscopic work the term diabase is superfluous, while we have and use basalt, dolerite and gabbro. It is, however, so intimately involved with the literature of many important mining regions and others of great geological interest that the student should be familiar with its employment and its significance. The name is derived from the Greek verb meaning to penetrate or pass through, and was suggested by the dikes in which the early occurrences were met. Greenstone and trap are also old names chiefly applied to diabase.

Into many basalts, nepheline or leucite enter, and if in notable amount, with little or no olivine, the rock is called tephrite, or leucite-tephrite; if with much olivine, basanite or leucite-basanite; if with little or no olivine and no plagioclase, nephelinite or leucitite; and if there is much olivine, nepheline-basalt and leucite-basalt. The distinctions are, however, microscopic and in the field basalt is sufficient. Again the rocks may lack both the feldspar and the feldspathoids and consist merely of augite in a glassy groundmass, *i. e.*, augitite, or of augite and olivine in a glassy groundmass, giving limburgite, but these are also only of microscopic moment, although the significance of the names should be understood. Basalts with melilite are the rarest of the group.

Basalts rather rarely have hornblende, but when this is present it is a deep brown variety known as basaltic hornblende. Biotite is also uncommon, except in the varieties with nepheline or leucite. A most extraordinary basalt has been met by J. S. Diller and others in our western volcanic regions that contains *quartz* in moderately large phenocrysts. The presence of this mineral in such basic rocks is most peculiar, but it is explained by assuming exceptional conditions of crystallization in the early history of the magma, leading to the separation of quartz which was never re-absorbed.

Alteration, Metamorphism.—The olivine of basaltic rocks is the first mineral to alter, and it soon becomes a network of serpentine veinlets enclosing unchanged nuclei. The augite also passes readily into chlorite and finally the feldspar kaolinizes. The prevalence of green, chloritic products suggested the name greenstone for the old diabases. The basaltic rocks are extremely important in connection with metamorphism, and the iron-mining regions around Lake Superior present superb illustrations of the process. The augite has the greatest tendency to pass into green hornblende, by what is called a "paramorphic" change, *i. e.*, a change in the mineral without change in the chemical composition and without, as in pseudomorphs, preserving the original form. Under shearing stresses and movements, accompanied by this paramorphic change, diabases, so-called, pass into hornblende-schists, and even chlorite-schists or green-schists, losing their massive structure entirely and becoming a very different rock, and one that can be traced to its original with great difficulty. Such hornblendic rocks are also called amphibolites.

Tuffs. Basaltic tuffs, agglomerates, breccias, etc., are well known and often accompany the massive flows. They mark an explosive stage of eruption before the actual outpouring of lava.

Distribution. Basaltic rocks are enormously developed in this country. The oldest strata are penetrated by numerous black, igneous dikes, in practically all their exposures. The New England seacoast is especially seamed by them, and hundreds may be met in a short distance. The Adirondacks and the White Mountains, the Highlands of New York and New Jersey, have many.

In the East are the intruded sheets of Triassic diabase, up to 500 feet in thickness, forming many of the most prominent landmarks, such as Cape Blomidon, N. S.; Mts. Tom and Holyoke, Mass.; East and West Rock, near New Haven, Conn.; the Palisades on the Hudson, and many dikes in the Richmond, Va., and Deep River, N. C., coal fields. Around Lake Superior, both in the iron and in the copper regions, are still greater sheets, for many thousands of feet of basalt (diabase) are present on Keweenaw Point. On the north shore near Port Arthur, the head-lands of Thunder Bay exhibit superb examples. The iron-bearing strata are penetrated by innumerable dikes. The greatest of all the American basaltic areas is, however, met in the Snake River region of southern Idaho and extends into eastern Oregon and Washington. Many thousands of square miles are covered with the dark lava and are locally called the "Lava Beds." In Colorado, as at the Table Mtns., near Golden, and Fisher's Peak, near Trinidad, there are prominent sheets, and the same is true of many other points in this State. In New Mexico, Arizona and Texas they are also met. The volcanoes of the Sandwich Islands are basaltic. Basaltic rocks with nepheline are scarcely known in the United States. Some minor dikes in the East, a volcanic neck at Pilot Knob, near Austin, Texas, dikes and sheets in Uvalde Co., Texas, and a few dikes at Cripple Creek, Colorado, are practically the only localities yet identified. Leucitic rocks, more phonolitic than basaltic, are known in the Leucite Hills, Wyo., and in Arkansas. Of basaltic affinities they occur in New Jersey, but these and the nepheline rocks are of small practical moment, although of great scientific interest.

Basalts have quite as great development abroad as here. The islands off the north coast of Scotland are famous localities, and many of the volcanic regions of the continent are no less well provided. The lavas of Etna are chiefly basaltic, and those of Vesuvius are remarkable for their richness in leucite. In India are the great basalt fields of the Deccan, which are comparable in extent with those of the Snake River region of the West.

CHAPTER V.

THE IGNEOUS ROCKS, CONTINUED. THE DIORITES, GABBROS, PYROXENITES AND PERIDOTITES. ULTRA-BASIC IGNEOUS ROCKS.

THE DIORITES.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	Na_2O.	K_2O.	Loss.	Sp.Gr.
1.	67.54	17.02	2.97	.34	2.94	1.51	4.62	2.28	.55	
2.	65.27	15.76	1.36	3.44	2.14	4.57	3.97	. .	.42	
3.	61.75	18.88	0.52	3.52	3.54	1.90	3.67	1.24	4.46	2.79
4.	58.05	18.00	2.49	4.56	6.17	3.55	3.64	2.18	.86	
5.	56.71	18.36	. .	6.45	6.11	3.92	3.52	2.38	. .	2.86
6.	52.35	15.72	2.90	7.32	8.98	7.36	2.81	1.32	1.35	
7.	50.47	18.73	4.19	4.92	8.82	3.48	4.62	3.56	.58	2.87
8.	48.98	17.76	2.14	6.52	8.36	2.09	6.77	2.08	4.50	
9.	48.19	16.79	18.37	. .	6.85	1.32	5.59	1.11	2.31	

1. Quartz-mica-diorite, Electric Peak, Yellowstone Park, J. P. Iddings, Anal. by Whitfield, Bull. Phil. Soc. of Washington, II, 206. 2. Quartz-augite-diorite, Watab, Minn., A. Streng, Neues Jahrbuch, 1877, 232. 3. Diorite. Pen-maen-mawr, Wales, J. A. Phillips, Q. J. G. S., XXXIII, 424, 1877. 4. Diorite, see under No. 1 5. Diorite, (granitoid andesite?) Comstock Lode, Nev., R. W. Woodward, 40th Par. Survey, I, opp. p. 676. 6. Augite-diorite, Little Falls, Minn., A. Streng, Neues Jahrb., 1877, 129. 7. Augite-diorite, Mt. Fairview, Custer Co., Colo., W. Cross, Anal. by Eakins, Col. Sci. Soc., 1887, 247. 8. Porphyritic-diorite, St. John, N. B., W. D. Matthew, Trans. N. Y. Acad. Sci., XIV, 213. 9. Diorite dike rich in magnetite, Forest of Dean Mine, N. Y., J. F. Kemp, A. J. S., Apr., 1888, 331.

Comments.—The analyses represent a series that is closely parallel with the dacites and andesites in the first five analyses, but that recalls the basalts and diabases in the last four. MgO rules lower than in the latter. It is evident that the prevailing feldspar would be a lime-soda variety, but that orthoclase might readily be produced, for even when we allow some for biotite the percentage of K_2O is notable. The parallelism with gabbros will be shown by the next table to be close.

Mineralogical Composition and Varieties.—The name diorite is derived from the Greek verb, meaning to distinguish in allusion to the fact that the hornblende and feldspar could be distinguished one from another in the coarsely crystalline ones first studied. Diorites are granitoid rocks consisting of hornblende, biotite and plagioclase. Those with hornblende are diorites proper, while those with biotite are called mica-diorites. Some augite is occasionally present, marking passages to the gabbros and giving the name augite-diorite. An intermediate type occurring in dikes, and containing both biotite and augite is kersantite. Acidic diorites often have considerable quartz, and are called quartz-diorites. Tonalite is a quartz-hornblende-diorite. Quartz-diorites shade insensibly into granites, and the importance of the intermediate forms or granite-diorites was emphasized under granite. These acidic diorites are prevailingly light in color; but the more basic ones become decidedly dark. Certain dikes with the minerals of diorite are called camptonites. The great tendency of augite to change to green hornblende causes a doubt to hang over the true character of many diorites. They may often be metamorphic products from gabbros or diabases.

Alteration, Metamorphism.—In ordinary alteration the feldspar of diorites kaolinizes and the hornblende changes to chlorite, affording one of the varieties of the so-called greenstones. In metamorphism the diorites pass into gneisses, under shearing stresses, and into hornblende schists or amphibolites. In many mining regions even decidedly schistose varieties are still called diorite. A final stage is chlorite-schist, wherein the hornblende has altered to chlorite.

Distribution. True, original diorites are not very common rocks in America. A well known quartz-mica-diorite is extensively developed in a series of igneous rocks, called the Cortlandt Series, on both sides of the Hudson, below Peekskill. In the Sudbury nickel district, north of Lake Huron, dense, dark diorites are the chief rock containing the ore, but there is always the possibility that the hornblende is altered augite. Mt. Davidson, above the Comstock Lode, is either a true diorite or a granitoid phase of andesite. Authorities differ as to its interpretation. Granodiorites, the intermediate rocks between granite and diorite, are well recognized both in the East and the West.

Diorites are well known abroad and have been described from various places in Great Britain, Germany, France and Austria. The typical tonalite is obtained near Meran, in the Tyrol,

THE GABBROS, PYROXENITES AND PERIDOTITES.

Gabbro.	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	Na_2O.	K_2O.	Loss.	Sp. Gr.
1.	59.55	25.62	0.75	. .	7.73	tr.	5.09	0.96	0.45	2,66
2.	55.34	16.37	0.77	7.54	7.51	5.05	4.06	2.03	0.58	
3.	54.72	17.79	2.08	6.03	6.84	5.85	3.02	3.01	. .	2.928
4.	54.47	26.45	1.30	0.67	10.80	0.69	4.37	0.92	0.53	2.72
5.	53.43	28.01	0.75	. .	11.24	0.63	4.85	0.96	tr.	2.67
6.	52.14	29.17	. .	3.26	10.81	0.76	3.02	0.98	0.58	
7.	49.15	21.90	6.60	4.54	8.22	3.03	3.83	1.61	1.92	
8.	48.02	17.50	1.80	7.83	13.16	10.21	1.48	tr.	.79	
9.	46.85	19.72	3.22	7.99	13.10	7.75	1.56	0.09	.56	
10.	46.85	18.00	6.16	8.76	10.17	8.43	2.19	0.09	.30	3.097
11.	45.66	16.44	0.66	13.90	7.23	11.57	2.13	.41	.07	
Pyroxenite.										
12.	55.14	0.25	3.48	4.73	8.39	26.66	.30	. .	. .	
13.	53.98	1.32	1.41	3.90	15.47	22.59	. .	. .	0.83	3.301
14.	44.01	11.76	15.01	. .	4.06	25.25	. .	. .	. .	
Peridotite.										
15.	47.41	6.39	7.06	4.80	14.32	15.34	.69	1.40	2.10	3.30
16.	46.03	9.27	2.72	9.94	3.53	25.04	1.48	0.87	0.64	3.228
17.	41.00	7.58	. . .	5.99	10.08	23.59	0.52	. .	4.73	2.989
18.	36.80	4.16	. .	8.33	8.63	25.98	0.17	2.48	0.51	
19.	33.84	5.88	7.04	5.16	9.46	22.96	0.33	2.04	7.50	
20.	29.81	2.01	5.16	4.35	7.69	32.41	0.11	0.20	8.92	2.78

1. Anorthosite, Chateau Richer, Canada, T. S. Hunt, Geology of Canada, 1863. 2. Norite, Cortland Series, Montrose Point, Hudson River, Anals. by Munn, for J. D. Dana, A. J. S., Aug., 1881, p. 104. 3. Gabbro, near Cornell Dam, Croton River, H. T. Vulté, for J. F. Kemp, unpublished. 4. Anorthosite, Summit of Mt. Marcy, Adirondacks, A. R. Leeds, 30th Ann. Rep., N. Y. State Museum, reprint, p. 14, 1876. 5. Anorthosite, Nain, Labrador, A. Wichmann, Z. d. d. g. Ges., 1884. 6. Gabbro, Iron Mtn., Wyo., 40th Parallel Surv., II., 14. 7. Gabbro, near Duluth, Minn., Streng, Neues Jahrb. 1876, 117. 8. Gabbro-diorite, Baltimore, Md., average of seventeen samples, Mackay for G. H. Williams, U. S. G. S., Bull., XXVIII., 37. 9. Gabbro, Baltimore average of twenty-three samples, ibid. 10. Gabbro, Southwest Adirondacks, C. H. Smyth, Jr., A. J. S., July, 1894, 61. 11. Gabbro, Northwest Minn., W. S. Bayley, Anals. by Stokes, Jour. Geol. I., 712. 12. Pyroxenite, var. Websterite, Webster, N. C., E. A. Schneider for Geo. H. Williams, Amer. Geol., July, 1890, p. 41. 13. Pyroxenite, Baltimore, Md., T. M. Chatard for G. H. Williams, ibid. 14. Pyroxenite, Meadow Creek, Mont., Geo. P. Merrill, Proc., U. S., Nat'l Mus., XVII., 658. 15. Peridotite, Cortland Series, Montrose Pt., N. Y., Emerson for G. H. Willams, A. J. S., Jan., 1886, 40. 16. Peridotite, Custer Co. Colo., L. G. Eakins for W. Cross, Proc. Colo. Sci. Soc., 1887, 245. 17. Peridotite, Baltimore, Md., L. Mackay for G. H. Williams, Amer. Geol., July, 1890, 39. 18. Peridotite, Dewitt, N. Y., H. S. Stokes for Darton and Kemp, Amer. Jour. Sci., June, 1895, 456. 19. Mica Peridotite, Crittenden Co., Ky., W. F. Hillebrand for J. S. Diller, A. J. S., Oct., 1892, 288. 20. Peridotite, Elliott Co., Ky., J. S. Diller, Bull. 38, U. S. G. S., p. 24.

Comments.—The range in composition presented by the gabbros is in many respects the same as that of the basalts. As a general rule the most feldspathic members (the anorthosites) are the highest in silica, Nos. 1, 4 and 5. No. 6, although described as gabbro, is doubtless of the same character, for the low FeO and MgO indicate few dark silicates. These rocks are also highest in Al_2O_3 of all the rock analyses yet quoted. As the CaO and MgO increase in amount, the pyroxenes and olivine grow notably more abundant. In the gabbros of the Cortland series (Nos. 2 and 3) and in those near Duluth (No. 7) there is often considerable orthoclase as is indicated by the K_2O. The pyroxenites are distinguished by the falling off in Al_2O_3, due to the disappearance of feldspar, and by the increase in CaO and MgO from the pyroxenes. The peridotites reach a lower percentage of silica than any other igneous rocks so far cited, but if this is accompanied by high H_2O, allowance must be made for the relative decrease of the original SiO_2 in the change to serpentine. The great percentages of MgO are very notable, and are due to the presenec of much olivine, magnesian pyroxene and, in instances, biotite. Chromic oxide is also always present in small amounts, and oxides of nickel and cobalt are usually in perceptible quantity.

Mineralogical Composition, Varieties.—The name gabbro is of Italian origin, and has been applied of recent years, and with growing favor to the great group of granitoid rocks consisting in the typical cases of plagioclase and pyroxene. The diabases, as explained under basalt, are now generally classed with the volcanic rocks, although texturally and mineralogically they really lap over true gabbros. The so-called gabbro group is a very large and characteristically variable one. Originally the name gabbro was only applied to a mixture of plagioclase and the variety of monoclinic pyroxene called diallage, that has pinacoidal as well as prismatic cleavages, but of late years all granitoid, plutonic pyroxene-plagioclase rocks are collectively spoken of as the gabbro group. At the acidic extreme we have in Canada and the Adirondacks enormous masses of rock that are practically pure, coarsely crystalline labradorite. Pyroxene is the dark silicate when any is present, but often it is insignificant. These pure feldspar rocks are best called *anorthosites*, from the French word for triclinic feldspar, but the word is not to be confused with anorthite, the lime-feldspar with which, it has no special connection. As monoclinic pyroxene increases they pass into gabbros proper. More or less biotite and hornblende may also be present. If the pyroxene is orthorhombic we call the rock norite. Varieties with olivine are frequent, giving olivine-gabbro and olivine-norite. Gabbros and norites are not readily distinguished without the microscope, unless the bronzy appearance of hypersthene can be recognized. Gabbro is then a good collective term. An old and obsolete synonym of anorthosite is labradorite-rock, of interest because widely used in the early reports on the Adirondacks. Norites were called hypersthene rock, or hypersthene-fels, both of which are undesirable rock names. Gabbro intrusions of not too great extent or irregularity for careful study have been observed to grow more basic toward the outer margins.

The gabbros pass insensibly, by the decrease of plagioclase, into the pyroxenites and peridotites, and in any great gabbro area all these are usually present, but they may occur also as independent masses. The pyroxenites are practically pyroxene, with little if any other minerals. There is some variety, according as the rock contains one or several of the following: enstatite, bronzite, hypersthene, diallage or augite; but with the unassisted eye, it is seldom that one can be sure of these distinctions, except as the orthorhombic pyroxenes exhibit a bronze luster. Hornblende, magnetite and pyrrhotite may also be present. With the accession of olivine, peridotite results, so named from the French word peridot for olivine, and a number of varieties have been made according as the olivine is associated with one or more of the minerals cited for pyroxenites. The distinctions are however hardly possible without microscopic aid. As the extreme of peridotites we have a nearly pure olivine rock, called dunite, important in North Carolina. Much magnetite may be associated with peridotite; indeed at Cumberland Hill, R. I., there is enough to almost make the rock an ore, Chromite, too, is a frequent associate. As peridotites shade into a porphyritic texture, especially in dikes, they have been called picrites, and even further varieties, such as kimberleyite, have been made. Black hornblende, which is brown in thin sections, is frequent in both pyroxenites and peridotites, and may even form a rock itself, hornblendite. Dark brown biotite is also often present in considerable amount.

Some writers have regarded the pyroxenites and peridotites as of doubtful igneous origin and have placed them with metamorphic rocks, but from their frequent association with gabbro, and from their independent occurrence in dikes, there is no good reason to doubt their true, igneous nature.

A very rare granitoid rock, consisting of plagioclase, nepheline and ferro-magnesian silicates has been called theralite from the Greek verb to seek eagerly, because its discovery was anticipated before it was actually found by J. E. Wolff in the Crazy Mountains, Montana. It is an extremely rare combination of minerals, but of special scientific interest because it corresponds among the granitoid rocks to the tephrites and basanites of the porphyritic.

Alteration, Metamorphism.—The gabbros alter chiefly by the formation of serpentine and chlorite from the dark silicates. The pyroxenites and peridotites change readily into serpentine, often with an intermediate stage as hornblende-schist. Under dynamic stresses, especially shearing, anorthosites and gabbros pass into gneissoid types, and in the process much garnet may be developed. This is especially true in the Adirondacks. The larger feldspars may be left in the gneisses as "eyes," or to adopt the German term, as "Augen," affording Augen-gneiss, *i. e.*, gneisses with comparatively large lenticular feldspars. Much hornblende, especially in true gabbros, is often developed in the process. The basic members, the pyroxenites and peridotites develop amphibolites or hornblende-schists, which latter often furnish very puzzling geological problems.

Distribution.—The anorthosites are so far as we know limited to several Canadian areas, as at the headwaters of the Saguenay river, and again north of Montreal; and to the higher peaks of the Adirondacks and some of their outliers. Mt. Marcy and its neighbors consist of them. Gabbros are also present in vast quantity, and are likewise well known in the White Mountains, in the famous Cortlandt series, near Peekskill, on the Hudson, and in the vicinity of Baltimore. Around Lake Superior gabbros are of great importance, as the basal members of the Keweenawan system and other older intrusions are largely formed of them. Fine specimens can be had at Duluth. They are a characteristic wall rock of titaniferous magnetite. Pyroxenites occur as subordinate members of the gabbro areas, especially near Baltimore. Peridotites are in the same relations in the Cortlandt series, in the Baltimore area and in North Carolina. They are also known on Little Deer Island, Me.; at Cumberland Hill, R. I.; in the dikes near Syracuse,

N. Y.; at Presqu' Isle, near Marquette, Mich.; in Kentucky; in California and elsewhere in the West. When outlying dikes are met, far from any visible, parent mass of igneous rock and in sedimentary walls, they are very frequently peridotite.

Abroad, anorthosites and gabbros are abundant in the Scandinavian peninsula, whose geology is in many respects like that of Canada and the Adirondacks. In the north of Scotland gabbros are of especial interest because they have been shown by Judd to be the deep-seated representives of the surface basalts. On the continent they are important rocks in many localities. The same is true of Australia and such other parts of the world as have been studied. Of especial interest are the peridotite dikes in South Africa that have proved to be the matrix of the diamond.

ULTRA-BASIC IGNEOUS ROCKS. METEORITES.

A few ultra basic igneous rocks are known in which the silica decreases almost to nil, and in which the bases, especially iron, are correspondingly high. They are in general rather to be considered as basic segregations in a cooling and crystallizing magma than as individual intrusions. The Cumberland Hill, R. I., so-called peridotite, cited above, has very little silica. Titaniferous ores have almost none, but they are often exceptionally rich in alumina. In a few cases metallic iron has been detected in basic igneous rocks, suggesting analogies with meteorites.

Meteorites are rare and only of scientific interest, but it is extremely suggestive that such silicates as are met in them are chiefly olivine and enstatite, minerals rather characteristic of very basic rocks. The commoner meteorites are an alloy of metallic iron and nickel, but some rare sulphides are occasionally present.

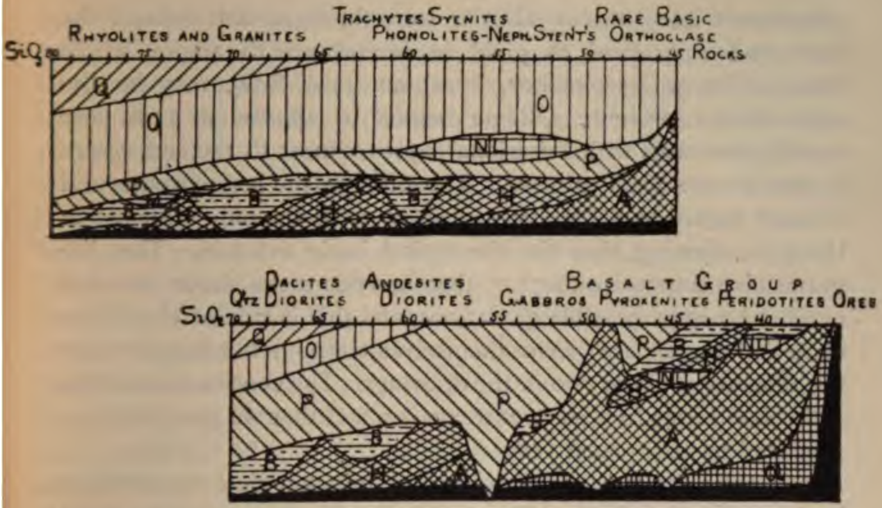
As filling out the theoretical series we cannot bar out water and ice. There is no reason why they are not to be considered igneous rocks of extremely low fusing point, but they are so familiar that a simple reference to them is sufficient.

CHAPTER VI.

REMARKS IN REVIEW OF THE IGNEOUS ROCKS.

Chemical Composition. Igneous magmas vary from about 80% silica as a maximum to practically none as a minimum, but important rocks rarely drop below 40 . Alumina is highest in the anorthosites or feldspathic gabbros, where it may exceed 25%. It is lowest in the pyroxenites and may be less than 1%. The oxides of iron are almost lacking in the highly siliceous, but may reach beyond 20% in the basaltic rocks, and with TiO_2 may be nearly 100% in some igneous iron ores. Lime attains its maximum of 12–15% in the gabbros and pyroxenites, while magnesia in the pyroxenites and peridotites may even surpass 25%. Potash is most abundant in the granites and leucite rocks; soda in those with nepheline. Combined alkalies may reach 15% in the phonolites and nepheline-syenites. In general they are, however, about 4–10, and may practically fail. Water in quantities over 1% as a rule is an indication of decay, but in the pitchstones this is not positively true, for the water reaches close to 10% and the rocks are apparently unaltered.

Texture. All three of the typical textures are easily recognized in characteristic development, but the glassy shade insensibly into the felsitic, the felsitic into the porphyritic, and the porphyritic into the granitoid. There are, therefore, intermediate forms that are difficult to classify. Yet, on the whole, the four textures are the most satisfactory basis for classification, and as a guide, in accordance with which to study. Chemical composition being the same, ***texture is a result of the physical conditions surrounding the magma at the time of crystallization and of the presence of mineralizers.***



Diagrams intended to illustrate graphically the mineralogical composition of the igneous rocks. The numbers indicate percentages in silica. The upper diagram includes the orthoclase rocks, the lower the plagioclase and non-feldspathic ones. Q is quartz; O, orthoclase; NL, nepheline and leucite; P, plagioclase; M, muscovite; B, biotite; H, hornblende: A, augite; Ol, olivine; the black area, magnetite, pyrrhotite, and other metallic minerals.

Mineralogy. The above diagrams, with a reasonable approximation to the truth, illustrate the quantitative mineralogy of the igneous rocks. A section cut through the charts at any one point expresses the relative amounts as well as kinds of the several minerals in the rocks whose names are along the top lines, and whose percentages in silica are approximately shown. No mention is made of texture. In the orthoclase rocks quartz disappears at about 65% SiO_2, while orthoclase continues to the end; plagioclase in small amount is quite constantly present throughout the series. Nepheline and leucite come in as indicated. Muscovite appears only in the more acidic granites. Biotite and hornblende vary in relative quantity, but toward the basic end both yield to augite. The rocks at the basic end are chiefly those recently discovered by Weed and Pirsson in Montana, by Iddings in the Yellowstone Park and by Lawson in the Rainy Lake region. In the plagioclase and non-feldspathic rocks quartz and orthoclase soon run out, so far as any notable or regular amount is concerned. Plagioclase holds along to about 45% SiO_2, and at about 55% SiO_2 may in the anorthosites be the only mineral present. Biotite and hornblende are present all the way through, but toward the basic end they tend to yield in importance to augite, which latter in some pyroxenites, at about 49% SiO_2, may be the only silicate present. Olivine begins to appear at 55% and steadily increases with occasional lapses almost to the end, where it may be the chief mineral. The ores, as the last extreme, and without regard to silica, increase so as to be the only minerals in the rock, forming thus the theoretical basic extreme. The diagrams also emphasize the fact that igneous rocks shade into one another by imperceptible gradations, and this is true of the orthoclase and plagioclase groups themselves, although not suggested by the separation of the two in the drawings. The continuation of the orthoclase series to a basic extreme is a fact that we have only appreciated in very recent years.

A careful scrutiny of analyses and mineralogical composition leads to the conclusion that practically the same magma may, under different physical conditions of crystallization, afford mineralogical aggregates that vary considerably in the proportions of the several minerals—now yielding more hornblende, again more augite, and even affording quartz in a basalt. Hence, analyses in different groups overlap more or less, and the difficulty of drawing sharp lines of distinction is increased. Yet, allowing for this variation, chemical composition determines the resulting mineralogical aggregate and is fairly characteristic.

Determination of Igneous Rocks. In determining an igneous rock, the texture should first be regarded, next the feldspars. If orthoclase prevails, the presence or absence of quartz establishes the rock. If plagioclase prevails, we look for biotite, hornblende, pyroxene and olivine. If no feldspar is present we look for the presence or absence of olivine. On this basis the table on page 18~~54~~ is to used—there are, however, many finely crystalline rocks which elude the power of the unassisted eye. If of light shades, they can generally be referred with reasonable correctness to the rhyolites, trachytes or felsites. If dark, the name "trap" is a very useful and sufficiently non-committal term. While books are of great assistance, really the only way to become properly familiar with rocks, is to use the books in connection with correctly labeled and sufficiently complete study collections.

Field Observations. A rock is not to be considered by any intelligent observer as a dead inert mass in nature, but as an important participant in the ceaseless round of changes that confront us on every side. Familiarity with specimens and varieties in collections ought always to be followed by observation in the field. We have all grown to believe that in limited areas igneous rocks, however, varied, they may be, are yet intimately related in their origin, or are bound together by ties of kinship, " consanguinity " as Iddings has called it. Some regions like eastern Montana and the Black Hills have especial richness of high soda or potash magmas, giving rise to nepheline and leucite rocks, and sodalite syenites; Colorado, Utah and New Mexico have wonderful and enormous laccolites of andesities (porphyrites). The Pacific coast in South America has andesites in vast extent from active volcanoes, and in North America from extinct cones. Idaho, Oregon and Washington are marked by basalts. The Atlantic coast region has a long series of very ancient volcanoes, that preceded the early fossiliferous strata from Newfoundland to North Carolina and that yielded nearly the entire series of the volcanic rocks. In the Adirondacks, on the Hudson near Peekskill, near Baltimore and around Lake Superior we find the members of the gabbro family; while near tidewater along the Atlantic seaboard we have granites, almost all with biotite. Such facts as these suggested the creation of the term "petrographic provinces," to J. W. Judd, in the endeavor to suggest these kinships of magmas in certain limited districts. There are many others even in North America that could be cited, but the above will suffice to remind the reader that these broader relationships should be always before him while extending his acquaintance with rocks as they occur in the natural world about him.

CHAPTER VII.

THE AQUEOUS AND EOLIAN ROCKS. INTRODUCTION. THE BRECCIAS AND MECHANICAL SEDIMENTS NOT LIMESTONES.

The members of this, the second grand division, are much simpler, and, as a general thing, much easier to identify and to understand than are the igneous. No single term is comprehensive enough to include them all, and even the double one selected above, in the endeavor to embrace as many as possible, and to avoid the multiplication of grand divisions, still falls short of including several. Nevertheless, those not embraced (the breccias) are of limited distribution, and, for many reasons, go best with the other fragmental rocks, even if, strictly speaking, they are neither aqueous nor eolian in origin. Sedimentary is a most useful term, and is universally applied as a partial synonym of the above, for it fairly includes the most important members of the series, but the rocks deposited from solution and the eolian rocks can hardly be understood by it.

The rocks will be taken up under the following groups:

I. Breccias and Mechanical Sediments, not Limestones.
II. Limestones.
III. Organic Remains, not Limestones.
IV. Precipitates from Solution.

The limestones are reserved for a special group, although they belong in instances to each of the other three. They form, however, such an important series in their scientific and practical relations, that it is in many respects advantageous to take them all up together.

I. BRECCIAS AND MECHANICAL SEDIMENTS, NOT LIMESTONES.

Group I. is described in order from coarse to fine in the following series, minor varieties not cited in the table being mentioned in the text under their nearest relatives.

Coarse			to		Fine.
Breccia.	Gravel and Conglomerate.	Sand and Sandstone.	Argillaceous Sandstone.	Silt and Shale.	Clay.
			Calcareous Sandstone.	Calcareous Shale.	Marl.

BRECCIAS.

The word breccia is of Italian origin and is used to describe aggregates of *angular* fragments cemented together into a coherent mass. The breccias cannot all be properly considered to be either aqueous or eolian, and some have already been referred to under the fragmental igneous rocks. Oftentimes they resemble conglomerates, but, unless formed of fragments of some soluble rock, whose edges have become rounded by solution, there is no difficulty in distinguishing them. Breccias, as regards their angular fragments and interstitial filling, may be of the same materials or of different ones. We may distinguish *Friction breccias* (Fault breccias), *Talus breccias*, and, for the sake of completeness, may also mention here *Eruptive breccias.*

Friction breccias are caused during earth-movements by the rubbing of the walls of a fault on each other, and by the consequent crushing of the rock. The crushed material of finest grade fills in the interstices between the coarser angular fragments, and all the aggregate is soon cemented together by circulating mineral waters. Such breccias occur in all rocks and are a frequent source of ores which are introduced into the interstices by infiltrating solutions. Quartz and calcite are the commonest cements.

Talus breccias are formed by the angular debris that falls at the foot of cliffs and that becomes cemented together by circulating waters, chiefly those charged with lime.

Eruptive breccias may be produced either by the consolidation of coarse and fine fragmental ejectments like tuffs, or by an erupting sheet or dike that gathers in from the wall rock sufficient fragments as inclusions to make up the greater part of its substance. These are finally cemented together by the igneous rock itself and afford curious and interesting aggregates, oftentimes representing all the rocks through which the dike has forced its way to the surface.

A crust may also chill on a lava stream, and when an added impulse starts anew the flowing, the crust may be shattered into an eruptive breccia of a still different type.

We often speak of breccias as "brecciated limestone," "brecciated gneiss," or some other rock, making thus the character of the original prominent. When the fragments and the cement are contrasted in color, very beautiful ornamental stones result, which may be susceptible of a high polish.

A moment's consideration of the above methods of origin will convince the reader that breccias, except as formed of loose volcanic ejectments are of very limited occurrence. Although deeply buried rocks that share in profound earth movements often suffer crushing and brecciation on a large scale, the effects are chiefly detected by microscopical study.

GENERALITIES REGARDING SEDIMENTATION.

In the production of the rocks next taken up, moving water plays so prominent a part that its general laws are described by way of necessary introduction. All streams or currents charged with suspended materials exercise a sorting action during the deposition of their loads. With materials of the same density the sorting will grade the deposit according to the sizes of the particles. With materials of different densities, smaller particles of heavier substances will be mixed with larger particles of lighter ones. Assuming a swift current, it readily appears that when it slows up, the large and heavy fragments drop first of all; then the smaller fragments of the heavier materials and the larger ones of those successively lighter, until at last the smallest particles of the lightest rock alone remain in suspension. It is also important to bear in mind that, the density being the same, the size of the transportable particle increases with the sixth power of the velocity. Thus, if we have a current of the proper velocity it will be able to lift a grain of quartz a sixteenth of an inch in diameter; but if the velocity is doubled, the transportable particle will be four inches in diameter. An appreciation of this law makes the size of boulders moved by many streams, in times of flood, less surprising. On the other hand, when the suspended material becomes excessively fine, the ratio of its surface to its volume is so extremely high that adhesion, or chemical action akin to hydration, or some other influence not well understood, operates in pure, fresh waters so as to practically render sedimentation impossible, even if the medium is perfectly quiet. W. M. Brewer has shown by a series of experiments with all sorts of clays, lasting over many years, that if we introduce into such an emulsion a mineral acid or a solution of salt, or of some alkali, the turbidity clears with remarkable quickness. When, therefore, sediment-laden streams flow into the ocean, or into salt lakes, even the finest part of their load speedily settles out.

While we may state thus simply the laws of sedimentation, we must not expect in Nature such well-sorted and differentiated results as would at first thought appear to be the rule. Of rivers and shore currents—the two great transporting agents—the former are subject to floods and freshets, giving enormously increased efficiency for limited periods, and again to droughts, with the same at a minimum. Hence varying sediments overlap and are involved together. Eddies and quiet portions in the streams themselves contribute further confusion, and an intermingling of coarse and fine materials. Shore currents have parallel increases of violence in times of high wind and storms, and sink again in times of calm.

Eolian deposits are subject to even greater fluctuation, and their irregularities are more pronounced than those of the true Aqueous. Both these classes of rocks are marked by a more or less perfect arrangement of their materials in layers. The layers give rise to regular beds in deposits from quiet and uniform currents, and, although in those from swift ones they are very irregular, as explained above, nevertheless *bedding*, or *stratification*, is in the highest degree characteristic of the Aqueous and Eolian grand division.

When in the presence of these sedimentary rocks in the field, the observer should always appreciate that they reproduce past conditions, and that they indicate the former presence of water, either in a state of agitation and with high transporting power for the coarse varieties, or as quiet reaches in which were laid down the finer deposits. Rightly appreciating and interpreting them, we may see that the ocean has advanced across the land in times of submergence, leaving behind its widening trail of shore gravels, now conglomerates; that these have been followed up and buried first by fine offshore sediments, and later by the remains of organisms now appearing as limestones, until succeeding elevation causes the waters again to retreat and prepare the way for another "cycle of deposition."

GRAVELS AND CONGLOMERATES.

Loose aggregates of rounded and water-worn pebbles and boulders are called gravels, and when they become cemented together into coherent rocks they form conglomerates. Sand almost always fills the interstices. Silica, calcite and limonite are the commonest cement. The component pebbles are of all sorts of rock depending on the ledges that have supplied them, hard rocks of course predominating. Rounded fragments of vein quartz are especially frequent. Gravels and conglomerates, if of limited extent, indicate the former presence of swift streams; if of wide area they suggest the former existence of sea beaches and the advance of the sea over the land. Component pebbles are of course older than the conglomerate itself, and if igneous, they may establish the age of the intrusion as older than the conglomerate. Fossiliferous boulders prove the age of the conglomerate as later than their parent strata. Under favorable circumstances gravels may be cemented to conglomerates in a comparatively few years. Conglomerates are exclusively aqueous. Gravels and conglomerates graduate by imperceptible stages into pebbly sands and sandstones, and these into typical sands and sandstones. Notably unsorted aggregates of relatively large and more or less angular boulders in fine sands or clay indicate glacial action.

Metamorphism. Under dynamic stresses, especially in the nature of pressure and shearing, the pebbles of a conglomerate may be flattened and rolled out into lenses, and such are often observed. If the pebbles are feldspathic as is the case in those from granite ledges, and if the interstitial filling is aluminous and not purely quartzose as in the commonest cases, conglomerates, when recrystallized, may pass into augen-gneisses with their characteristic "augen," or "eyes" of feldspar and quartz that but faintly suggest their original character. Excessive metamorphism may further develop types closely simulating granite, forming thus the so-called "recomposed granite" of the Lake Superior regions

Occurrence. Gravels are too familiar to require further reference. Conglomerates are met in all extended sedimentary series. Our greatest one lies at the base of the productive Coal Measures of Pennsylvania and adjacent States. It is properly called the "Great Conglomerate." Remarkable ones with squeezed pebbles are met in the Marquette iron region of Michigan. In Central Massachusetts there is an augen-gneiss, that has been derived from a Cambrian conglomerate. It is quarried at Munson, and sold as granite, and is a widely known building stone. Around Narragansett Bay, R. I., are conglomerates, in part at least of Carboniferous age, in all stages in the progress to gneiss.

SANDS AND SANDSTONES.

	SiO_2.	Al_2O_3.	FeO Fe_2O_3.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	Loss.	Sp. Gr.
1.	99.78	0.22	. .	. .	. .	. .	. .	. .	. .	
2.	98.84	0.17	0.34	tr.	tr.	tr.	. .	. .	0.23	
3.	99.62	. .	0.13	0.7	. .	. .	. .	. .	. .	
4.	99.47	0.17	0.12	. .	0.90	0.50	0.07	0.15	0.12	2.648
5.	95.85	2 64		. .	0.81	0.08	. .	. .	0.45	(2.245)
6.	94.73	0.36	2.64	. .	0.38	0.36	. .	. .	0.83	
7.	91.67	6.92	tr.	. .	0.28	0.34	. .	. .	1.17	2.240
8.	82.52	7.07	3.55	1.42	1.83	tr.	tr.	tr.	3.61	
9.	69.94	13.15	2.48	0.70	3.09	tr.	3.30	5.43	1.01	(2.36)

1. Sand from Cambrian Quartzite, Chesire, Mass., S. Dana Hayes, *Mineral Resources*, 1883–'84, p. 962. 2. Oriskany Sandstone, Juniata Valley, Penna. A. S. McCreath, *Idem.* 3. Siluro-Cambrian saccharoidal sandstone, Crystal City, Mo. Analyzed by Glass Co. 0.22 not determined, *Idem.* 4. Novaculite, Rockport, Ark. R. N. Brackett, for L. S. Griswold, Geol. Ark., 1890, III. 161. 5. Salmon-red Triassic Sandstone, Glencoe, Colo. Quoted by G. P. Merrill, "Stones for Building and Decoration," p. 420. The Sp. Gr. is of one from Ralston, near by. 6. Cambrian red Sandstone, Portage Lake, Mich., *Idem.* 7. Light-gray sub-carboniferous sandstone, near Cleveland, Ohio, *Idem.* 8. Olive-green carboniferous sandstone, Dorchester, N. B., *Idem.* 9. Red triassic sandstone (brownstone, arkose), Portland, Conn., *Idem.*

Comments on the Analyses. The first three illustrate the purity of the sand in exceptional cases. We may properly infer that the sediments were derived either from preëxisting sandstones, that had already been once sorted and separated from their aluminous ingredients, or from excessively weathered and kaolinized quartzose rocks, such that the feldspar had entirely passed into clay, and had been eliminated in deposition. No. 4 is a novaculite, and is an excessively fine, fragmental deposit. Nos. 5, 6 and 9 are red sandstones, and indicate the comparatively small percentage of iron oxides that may cause a deep coloration. No. 7 is free from iron, but has some aluminous material, evidently a very pure clay, from the lack of iron. No. 8 has its iron as protoxide, for the rock is a green variety. Its manganese oxide is worthy of remark. No. 9 is a feldspathic sandstone, or arkose, whose analysis, except that the Al_2O_3 is low and the CaO rather high, might answer for a granite.

The specific gravity of sandstones varies widely. Quartz itself is 2.6–2.66, and specially dense sandstones reach 2.5, but, being characteristically porous rocks, the usual range is 2.2–2.4. They often go lower and may even reach 1.8.

Mineralogical Composition, Varieties. The mechanical sediments whose predominant particles are finer than pebbles, and yet, in most cases, of notable size, are grouped under this head. They are found in all stages of coherence, from loose sands to excessively hard metamorphic rocks called quartzites. Quartz is much the commonest mineral that contributes the grains, as it is the most resistant of the common rock-making minerals. In river sands the grains are angular, but in those continually swashed together on a sea beach, they become more or less rounded. Garnets, magnetite, zircon and other hard and resistant minerals are widely distributed in small quantities. Feldspathic sands also occur, and when they are compacted to firm rock they are called arkose. As in the conglomerates, the cementing materials of sandstones are silica, calcite and limonite, but in many the character or cause of the bond is rather obscure. Those with siliceous cement yield the most durable stone for structural purposes; those with ferruginous afford the greatest range of colors, such as olive-green, yellow, brown and red. Calcareous cements may be detected by their feeble effervescence. Sandstones entirely formed of calcareous fragments are known, but are described under limestone.

A curious and exceptional rock is novaculite, that is extensively developed in Arkansas. It was long thought to be allied to the cherts, which it much resembles, but microscopic investigation has led Griswold to determine it to be a finely fragmental deposit of quartz grains, practically a siliceous ooze. In fineness it is parallel with the clays, but it contains little else than silica.

Aqueous sandstones generally exhibit well-marked bedding planes, although cases are familiar in which the bedding is excessively coarse and the layers are extremely thick. Swirling eddies in the original stream or currents give rise to cross-bedding and various irregularities. In fact, all the phenomena of beaches and stream-bottoms, such as ripple-marks, worm-borings, shells, etc., are preserved in sandstones.

Eolian sands are usually of aqueous deposition in their original condition, but they are afterwards taken up by the wind and driven along as dunes and dust into more or less remote districts. When they finally reach a state of rest and consolidate they have very irregular stratification, cross-bedding, swirling curves, pinching and swelling layers and other characteristic phenomena. Finer varieties afford a surface deposit that is generally called "loess," and that may lack all stratification. More or less water-transported material is also intermingled, making the term one of not particularly sharp definition. This mixed character has made the loess of many localities a rather puzzling geological problem. It is always loosely textured and is important in its relations to agriculture.

Sands and sandstones pass by insensible gradations into the varieties in the upper line of the series shown in the tabulation on p. 59 by the increasing admixture of clayey or argillaceous materials. The base is kaolin, Al_2O_3, $2\,SiO_2$, $2\,H_2O$, a mineral that forms microscopic, scaly crystals and that has the property of plasticity, and this property it lends to the last members of the series, which in exceptional cases may contain little else. The lower series passes gradually into the fragmental limestones, by the increasing admixture of calcite.

Metamorphism. The purer sandstones in metamorphism yield quartzites which are denser and harder than their originals, because by deposition of cementing quartz, the fragmental grains are very firmly bound together. The later deposited quartz often conforms to the optical and crystallographic properties of the grain around which it crystallizes. No sharp line divides sandstones and quartzites; they shade imperceptibly into one another. Less pure sandstones, if crushed and sheared in the metamorphic process, yield siliceous or quartz schists from the development of micaceous scales between the grains. Flexible sandstone or itacolumite, appears to owe to them its property of bending.

Occurrence. Sandstones are so common in all extended geological sections as to deserve slight special mention. Next to limestones they are the most widely used of building stones in quantity, although the annual value of granite is greater. The Potsdam sandstone of the Cambrian in New York and on the south shore of Lake Superior is extensively quarried, and other prominent ones are the Medina of New York, the Berea grit of the Subcarboniferous of Ohio; and the red and brown Triassic sandstones both of the Atlantic seaboard and the Rocky Mountains.

ARGILLACEOUS SANDSTONE, SHALE, CLAY.

	(a)SiO_2	(b)SiO_2	Al_2O_3	FeO Fe_2O_3	CaO	MgO	K_2O	Na_2O	(a)H_2O	(b)H_2O
1.		63.31	16.16	3.79	0.15	4.44	7.56	1.54	2.65	
Shale.										
2.		69.92	23.46	0.20	0.48	0.40	1.43		3.84	
3.		67.29	15.85	6.16	0.95	0.19	8.71		. .	
4.		64.37	19.73	9.07	0.82	2.32	3.78		. .	
5.		62.86	20.65	9.21	0.48	0.34	. . .		6.26	
6.		58.45	21.96	8.43	1.05	1.57	4.00		6.51	
7.		43.13	40.87	3.44	8.90	5.32	2.42		0.20	
Brick Clay.										
8.		81.71	9.81	3.80	0.48	0.26	. .		3.91	
9.		75.88	11.22	5.04	0.48	0.35	. .		6.76	
10.		65.14	13.38	7.65	2.18	2.36	8.51		. .	
11.		62.00	18.10	9.11	. .	. .	. .		5.66	
12.		57.80	22.60		1.85	2.07	. .		12.68	
13.		53.77	20.49	9.23	2.04	4.22	9.60			
14.		45.73	29.69	6.86	0.44	1.01	3.42		12.86	
Potters' Clay.										
15.	27.68	36.58	22.95	1.28	0.45	0.37	1.96		6.74	2.05
16.	42.28	18.02	24.12	1.46	0.59	0.68	2.42		7.77	0.86
Fire Clay.										
17.		61.60	28.38	0.52	0.46	0.36	. .		5.08	
18.	38.10	12.70	31.53	0.92	. .	tr	0.40		11.30	2.50
19.		45.29	40.07	1.07	0.26	0.08	0.48		13.18	
Residual Clay.										
20.		55.42	22.17	8.30	0.15	1.45	2.49		9.86	
21.		33.55	30.18	1.98	3.89	0.26	1.57		10.72	
22.		46.50	39.57	. .	. .	. .	. .		13.93	

NOTE. Where two values of SiO_2 are given, the first is the combined silica, *i. e.*, chiefly in kaolin, and the second the free silica, which is practically comminuted quartz. Under H_2O, where two values are given, the first is combined water, likewise chiefly in kaolin, the second is the free water, which has simply soaked in.

1. Argillaceous sandstone, Chickies Station, Penn. R. R., Geol. Surv. Penn. Rep. M, 91. 2. Haydensville, Hocking Co., O. Quoted by H. Ries, *XVI. Ann. Rep. Director U. S. Geol. Survey, Part IV.*, p. 572. 3. Hornellsville, Steuben Co., N. Y., *Ibid.* 572. 4. Kansas City, Mo., *Ibid.* 570. 5. Red Shale, Sharon, Mercer Co., Pa., *Ibid.* 572. 6. Leavenworth, Kan., *Ibid.* 570. 7. Clinton, Vermilion Co., Ind., *Ibid.* 570. 8. Washington, Daviess Co., Ind., *Idem.* 566. 9. Salem, Washington Co., Ind. *Idem.* 566. 10. Red Clay, Plattsburg, Clinton Co., N. Y., *Ibid.* 568. 11. Red Clay, Lasalle, Ill., *Ibid.* 564. 12. Rondout, N. Y., *Ibid.* 568. 13. Brown Clay, Fisher's Is., N. Y., *Ibid.* 568. 14. Hooversville, Somerset Co., Pa., *Ibid.* 568. 15. Akron, O., *Ibid.* 562. 16. East Liverpool, O., *Ibid.* 562, also TiO_2, 1.20. 17. Woodbridge, N. J., *Ibid* 556. 18. Cheltenham, Mo., *Ibid.* 556. 19. Woodland, Pa., *Ibid.* 556. 20. Morrisville, Calhoun Co., Ala., *Ibid.* 574. 21. Near Batesville, Ark., *Ibid.* 574, also P_2O_5, 2.53. 22. Pure Kaolin—Al_2O_3 $2SiO_2$, $2H_2O$.

Comments on the Analyses. The analyses are significant when compared with those of the sandstones on p. 63. It appears at once that there is a great decrease in silica, and a great increase in alumina, and, as a rule, in all the other bases and water. Among themselves there is wide variation, but by using No. 22, as indicating pure kaolin, it is possible to infer how much quartz sand is mingled with the clay, due allowance being made for the fragments of unaltered feldspar, as shown by the alkalies, for silicates, hydrous and anhydrous, involving iron, lime and magnesia, and for carbonates of lime, magnesia and iron. Shales and brick clays are shown to be comparatively impure admixtures of kaolin and quartz; potter's clay is much less so, and fire clay is little else than these two. No. 19 is practically pure kaolin.

Mineralogical Composition. Varieties. The argillaceous sandstones have a finer grain than the sandstones proper, and tend to form thin but tough beds. They find their best examples in the flagstones of our eastern cities. Shales lack this coherence and break readily into irregular slabs and wedge-shaped fragments of no notable size. As sands give rise to sandstones, so on hardening and drying, muds and silt yield shales. Shales show all grades from gritty and coarse varieties to fine and even ones approximating clays. The finer shales when ground have the same plasticity as clay, and are often moulded and baked into brick, especially of the vitrified kinds for paving. Shales may be black from bituminous matter in them, and are then described as "bituminous." They grade into cannel coals, but great areas of them such as the Genesee Shale of New York and the Huron Shale of Ohio, have as much as 8 to 20% hydrocarbons and yield quite copious products on distillation.

As the particles of quartz become finer and finer and not too abundant, the plasticity of the kaolin presently asserts itself so that the shales pass into clays. In the most even and homogeneous grades, they show but slight grit to the teeth, but in coarser varieties they are decidedly gritty even to the fingers. They are often separated into thin beds by layers of sand that mark the times of freshets and deposition of coarse material during their formation. Clays of earlier geological date are hard and dense rock and must be ground before use. Such are the fire-clays immediately beneath Carboniferous coal-seams. Clays are blue, red and brown according to the state of the iron oxide, whether ferrous or ferric, or they may be nearly white when it fails. The less pure brick clays as shown by the analyses contain oxides of iron, calcium, magnesium and of the alkalies in quantity, but fire-clays practically lack these.

As contrasted with the transported or sedimentary clays just mentioned, there are residual clays that result from the decay of impure limestones and that are found on their weathered outcrops. They are very impure and variable in composition, but they are markedly plastic.

Metamorphism. In metamorphic processes shales become compacted and oftentimes silicified. Their lack of homogeneity causes them to yield irregularly breaking and very tough rocks called graywackes, which differ only in greater hardness from their unaltered originals. Excessively silicified shales are called phthanites and are important in the Coast Range of California. Shales also under shearing stresses and attendant mineralogical reorganization pass into schists of various kinds, such as quartz-schist, mica-schist and possibly hornblende-schist. G. F. Becker even mentions rocks derived from them that are mineralogically like diabases and diorites, but their recognition is a matter for microscopic study. Clays under shearing stresses develop new cleavages without regard to their original bedding and from the homogeneous character of the original and the perfection of the cleavage, slates result, which are of great practical importance.

Occurrence. Shales and clays are such common members of extended geological sections as to deserve no special mention. They are often a thousand feet or more in thickness and cover great areas.

CALCAREOUS SANDSTONES, MARLS.

Calc. Sandst.	SiO_2	Al_2O_3	FeO Fe_2O_3	CaO	MgO	K_2O	Na_2O	CO_2	H_2O or Loss
1.	79.19	3.75		7.76	3.20	. .			3.26
2.	38.41	5.77	1.79	20.08	8.82	0.12	0.29		
Calc. Shales.									
3.	39.70	26.83		19.28	2.43	5.11			
4.	28.35	12.37		21.47	8.24	5.73			
Marls.									
5.	43.70	25.00		8.85	2.33	. .	. .	5.40	9.21
6.	38.70	10.20	18.63	9.07	1.50	3.65	. .	6.14	10.00
7.	28.78	11.63	2.96	24.50	2.91	2.12	. .	22.66	4.18

1. Calcareous sandstone, Flagstaff, Ariz. Quoted by G. P. Merrill, *Stones for Building and Decoration*, 420. 2. Calcareous sandstone, Jordan, Minn., *Idem.* 3. Genesee Shale, Mt. Morris, N, Y., supplied by H. Ries. 4. Niagara Shale, Rochester, N. Y., H. Vulté, analyst. Supplied by H. Ries. 5. Cretaceous Marl, Hop Brook, N. J. *Geol. of N. J.*, 1868, 419; also P_2O_5, 2.18. 6. Cretaceous Marl, Red Bank, N. J., *Idem*, 418; also P_2O_5, 1.14, SO_3 0.14. 7. Subcarboniferous marl, Bowling Green, Ky. *Ky. Geol. Surv.*, Chem. Analyses A, Part 3, 90; also, P_2O_5, 0.25.

Comments on the Analyses. The analyses illustrate in a very suggestive way the passage of these mechanical sediments into impure limestones. The gradual intermingling of more and more of shells and other remains of organisms brings it about. The high P_2O_5 of the marls, as cited under the references, is worthy of remark. It is to be appreciated that the lime and magnesia and some of the iron of the analyses are to be combined with CO_2, even though the CO_2 is not mentioned.

Mineralogical Composition. Varieties. Calcareous sandstones are practically sandstones with rich calcareous cement, or with a large amount of organic fragments intermingled with the prevailing quartz sand. They are passage forms to the fragmental limestones. Calcareous shales derive their lime partly from the fine organic sediment that is deposited with the siliceous and aluminous particles and partly from contained fossils. Beds of these rocks are particularly favorable layers for the discovery of the latter, and often break the monotonous barrenness of a geological section composed of ordinary shales. Marls, strictly speaking, are calcareous clays, and originate in typical cases by the deposit of limy slimes along with the aluminous. The lime destroys the plasticity of the clay and yields a crumbling rock, often richly provided with fossils and of value as a fertilizer. Grains of glauconite, the green silicate of potash and iron, are at times present, and characterize the so-called "green sands" that are valuable as fertilizers. The term marl is somewhat loosely used in its applications, and moderately coarse calcareous sands, and even beds that show but small percentages of lime on analysis are designated by it in the States along the Atlantic seaboard from New York south. It is clear that marls are intermediate rocks between clays and impure earthy limestones.

Metamorphism. The rocks of this group are altered in metamorphic processes to schistose forms, not so essentially different from those resulting from the common aluminous shales and clays, except that the richness in lime facilitates the production of minerals requiring it. The marls, when high in lime, behave like impure limestones, and are prolific sources of silicates. Marls are, however, much more common in later and unmetamorphosed formations than in older ones, although it may be that in the latter they have yielded some schistose derivatives not readily traced back to them.

Occurrence. Calcareous sandstones and shales are met as occasional beds in series of the more abundant, distinctively aluminous varieties. Marls are chiefly developed in the Cretaceous and Tertiary strata of the Atlantic seaboard and around the Gulf of Mexico. Fresh-water ones are not lacking in the Tertiary lake basins of the West.

CHAPTER VIII.

LIMESTONES; ORGANIC REMAINS, NOT LIMESTONES; ROCKS PRECIPITATED FROM SOLUTION. DETERMINATION OF THE AQUEOUS AND EOLIAN ROCKS.

II. LIMESTONES.

	SiO_2	Al_2O_3	FeO Fe_2O_3	CaO	MgO	CO_2	H_2O	Insol.	$CaCO_3$	$MgCO_3$
Living Organisms.										
1. (Coral)				54.57			2.54		97.46	
2. (Reef-rock)				53.82	1.01				96.11	2.13
3. (Lagoon Sed.)				54.58	.85				97.47	1.79
4. (Coral)				44.96	3.87				80.29	8.14
5. (Oyster Shells)				44.4	1.3	35.4	14.5		(79.28)	(2.73)
Calcite.										
6. Pure Mineral.				56.		44.			100.	
Dolomite.										
7. Pure Mineral.				30.43	21.72				54.35	45.65
Marine Limestones.										
8.	0.63		0.55	55.6	0.23				99.30	0.49
9.			1.06	53.78	0.34		0.90	1.13	96.04	0.72
10.			1.25	53.89	0.10				96.24	0.21
11.	1.84	0.64	1.82	51.40	2.23	41.19	0.27		91.80	4.68
12.	12.34		7.00	44.41	0.44				79.30	0.92
13.	3.77	0.08	6.80	33.79	15.32	42.21			60.35	32.61
	SiO_2	Al_2O_3	FeO Fe_2O_3	CaO	MgO	CO_2	H_2O	Insol.	$CaCO_3$	$MgCO_3$
14.			0.55	29.54	21.08		1.82	0.60	52.75	44.28
Waterlime.										
15.	18.34		7.49	37.60	1.48		3.94		67.14	2.90
16.	15.37		11.38	25.70	12.44		1.20		45.91	26.14
Siliceous.										
17.			1.20	17.69	10.59		1.24	43.72	31.60	22.24
Freshwater Limestone.										
18.			0.37	54.16	0.15	43.68		1.49	96.71	0.31
19.		1.83	0.22	34.20	0.11	26.79	4.64	31.28	61.07	0.23
Travertine.										
20.	0.08		0.15	53.83	0.90	41.79	1.43		94.97	0.43

1. Stag's horn coral, (*Millepora alcicornis*), S. P. Sharpless, *Amer. Jour. Sci.* Feb., 1871, 168. 2. Bermuda coral reef rock. A. G. Högbom, *Neues. Jahrb.*, 1894, I. 269. 3. Bermuda coarse lagoon sediment, *Idem.* 4. Average of 14 analyses of the coral *Lithothamnium* from localities the world over, *Idem*, 272. 5. Oyster shells, *Geol.*

of New Jersey, 1868, 405. 6. Calculated from $CaCO_3$. 7. Calculated from $CaCO_3$, $MgCO_3$. 8. Crystalline Siluro-Camb. limestone, Adams, Mass., E. E. Olcott for Marble Co. 9. Limestone, Bedford limestone, Ind. Quoted by T. C. Hopkins, *Mineral Industry*, 1894, 505. 10. Solenhofen lithographic stone. Quoted by G. P. Merrill, *Stones for Building and Decoration*, 415. 11. Limestone, Hudson, N. Y., Th. Egleston. 12. Trenton Limestone. Point Pleasant, Ohio, vide No. 10. 13. Surface Rock, Bonne Terre, Mo., J. T. Monell, *unpublished.* 14. Limestone, Chicago, T. C. Hopkins, *Mineral Industry*, 1895, 508. 15. Hydraulic limestone, Coplay, Penn. Quoted by W. A. Smith, *Mineral Industry*, 1893, 49. 16. Hydraulic limestone, Rosendale, N. Y., *Idem.* 17. Siliceous limestone, Chicago, Ill., vide No. 14. 18. Miocene limestone, Chalk Bluffs, Wyo., R. W. Woodward, 40th Parallel Surv. I. 542. 19. Eocene limestone, Henry's Forks, Wyo., B. E. Brewster, *Idem.* 20. Travertine, below Hotel Terrace, Yellowstone Park, J. E. Whitfield, for W. H. Weed, *9th Ann. Rep. Dir. U. S. Geol. Surv.*, 646.

Comments on the Analyses. The first three and the fifth analyses indicate that the calcareous parts of living organisms are quite pure calcium carbonate. The fourth analysis is of that species of coral which, so far as we know, is highest in magnesia. Small amounts of calcium phosphate are often present as well, some shells being richer than others. Nos. 6 and 7 are introduced so as to give a basis for estimating the purity of the following limestones: Nos. 8, 9 and 10 are extremely pure varieties, and from these, as a starting point, the other components increase in one analysis and another. No. 14 is a nearly typical dolomite. Nos. 12 and 17 are highly siliceous, and Nos. 15 and 16 are both strongly argillaceous. The last two are closely parallel in composition with marine varieties. An analysis of a travertine is given in No. 20.

It at once appears that Nos. 13, 14, 16 and 17 are far higher in magnesia than any known living organism, and it is evident that an original organic deposit must have undergone an enrichment in magnesium carbonate to bring them about. Dana suggested many years ago that coral or other organic sand, while agitated in sea-water, probably exchanges a part of its calcium for magnesium, and there is much reason to think that it does. Otherwise, the change must have been brought about by magnesian solutions percolating through the rock and altering it by the replacement process called dolomitization, or dolomization. Much of the silica, no doubt, results from radiolarians and sponge spicules, but much also, together with the alumina, from fine fragmental sediments.

Origin. Much the greater number of the important limestones are of marine origin, but in certain geological formations fresh-water ones are well developed. The calcareous remains of organisms have been their principal source, and of these the foraminifera, the corals, and the molluscs the chief contributors. Their shells have often become thoroughly comminuted to a calcareous slime before final deposition, so that the resulting rock affords no trace of organic structure. The solubility of the carbonate of lime aids in the cementation of the slime to rock and tends to efface the organic characters. Limestones pass by insensible gradations through more and more impure varieties into calcareous shales and marls, but, as a rule, they are deposited in deeper water than the true shales and sandstones. This conception must not be applied too strictly, because, beyond question, a depth of a few feet has often sufficed, and too much emphasis has often been placed upon the depth regarded as necessary for limestones. Coral sands accumulate on or near the immediate shore, and may even be heaped up by the wind.

In confined estuaries of sea water subjected to evaporation, enough carbonate of lime is precipitated directly from solution, to yield important strata, and such are often met in a series of beds associated with rock salt and other precipitated rocks as later set forth. Calcareous deposits from limy springs may also almost reach the dignity of rocks, and when abundant are called travertine or calcareous tufa. If particles of dust, etc., are suspended in limy springs or in concentrated estuarine waters, they gather concentric shells of the carbonate and may yield oölitic deposits from the coalescence of the concretions. Some algæ likewise secrete oölitic calcite and contribute extensively to rocks.

Mineral Composition. Varieties. Calcite is the chief mineral of limestones, and when thin sections are magnified it exhibits its characteristic cleavages. Dolomite and siderite accompany it frequently, and their molecules also replace the calcium carbonate, in a greater or less degree, to form double carbonates. An unbroken series can readily be traced from pure calcium carbonate, through more and more magnesian forms, to true dolomite. Those with over 5% MgO are usually described as magnesian limestone, and when the MgO mounts well toward the 21.72% in the mineral dolomite, we use the latter name. In the same way, a series of ferruginous varieties may be established toward the clay ironstone and black-band ores, and a siliceous series toward the flints and cherts. Cherty limestones are a very common variety, and are referred to again in connection with chert. When the argillaceous or clayey intermixtures enter, argillaceous or hydraulic varieties result that are generally drab and close-grained, and are useful in the manufacture of cement. Bituminous matter may be present, making the limestones black, and this, in the form of asphalt, may yield asphaltic varieties.

Besides these varieties established on the basis of chemical composition, special names may be given because of structure. Thus earthy limestones tend to crumble to dirt; oölitic limestones resemble the roe of fish; pisolitic varieties consist of concretions of size comparable with peas; and other terms are employed, that are self-explanatory. Prominent fossils suggest names, such as crinoidal, from fossil crinoids; coralline, foraminiferal and many more of local or stratigraphic significance. Practical applications play a part in nomenclature, supplying "waterlime," "cement-rock," "lithographic limestone," etc.

Metamorphism. Limestones feel the effects of metamorphism with exceptional readiness and under deforming stresses, probably accompanied by elevation of temperature, and in the presence of water, or along the contacts with intruded dikes and sheets of igneous rocks, they lose their sedimentary characteristics, such as bedding-planes and fossils, and change into crystalline marbles. The contained bituminous matter becomes graphite; the alumina and silica unite with the lime, magnesia and iron to give various silicates. Other oxides together with the bituminous ingredients contribute to the various colorations. Mechanical effects are manifested in flow lines, brecciation and other familiar features of many that are cut and polished for ornamental stones. Impure limestones that undergo these metamorphic changes are the most prolific of all rocks in variety and beauty of minerals. Arendal, Norway, and the crystalline limestone belt from Sparta, N. J., north through Franklin Furnace are good illustrations. The crystalline limestones will be again mentioned under the metamorphic rocks.

Occurrence. Limestones are too common to deserve special mention as regards occurrence. They are common rocks in all parts of the country, but the Trenton limestone of the Ordovician, the Niagara of the Silurian and the Sub-carboniferous limestones of the Mississippi Valley are specially worthy of note.

III. REMAINS OF ORGANISMS NOT LIMESTONES.

Calcareous remains are much the most important of the contributions made by organisms to rocks, but there are others, respectively siliceous, ferruginous and carbonaceous, that deserve mention.

SILICEOUS ORGANIC ROCKS.

The principal members of this group are infusorial or diatomaceous earths; siliceous sinters; and cherts, hornstones or flints, the three last names being practically synonymous. Infusorial earths consist of the abandoned frustules of diatoms, which are microscopic organisms belonging to the vegetable kingdom. Though not a common rock, they yet are met in series of sedimentary strata, both freshwater and marine, with sufficient frequency to justify their mention. Some foreign earthy materials are unavoidably deposited with them. The siliceous sinters are extracted from hot springs by algæ that, as shown by W. H. Weed, are capable of living and secreting silica in waters up to 185°F. They are far less important geologically than the infusorial earths. Chert is a rock consisting of chalcedonic and opaline silica, one or both. It possesses homogeneous texture and is usually associated with limestones, either as entire beds, or as isolated, included masses. It often has druses of quartz crystals in cavities, and in thin sections under the microscope it sometimes exhibits sponge spicules. Cherts not provided with these organic remains may be regarded with great reason as chemical precipitates, and as American varieties in the great majority of cases lack them the cherts receive more extended mention under the chemical precipitates.

Infus. Earths.	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	Na_2O.	K_2O.	H_2O.
1.	91.43	2.89		0.66	0.36	0.25	0.63	0.32	3.8
2.	86.90	4.09		1.26	0.14	0.51	0.77	0.41	5.99
3.	75.86	9.88	2.92		0.29	0.69	0.08	0.02	8.37
Silic. Sinter.									
4.	89.54	2.12		tr.	1.71	tr.	1.12	0.30	5.13
Chert.					$CaCO_3$.	$MgCO_3$.			
5.	34.0	0.80			63.4	1.5		0.3	

1. Miocene, Little Truckee River, Nev., R, W. Woodward, 40th Parallel Survey, I. opposite p. 542. 2. Fossil Hill, Nev., *Idem*. 3. Richmond, Va., M. J. Cabell, Mineral Resources, 1883–84, p. 721. 4. Deposit from Old Faithful, Yellowstone Park, J. E. Whitfield, for W. H. Weed, 9th Ann. Rep. Dir. U. S. Geol. Sur., 670. 5. Cretaceous chert, England, Jukes-Brown and Hill, Quar. Jour. Geol. Soc., Aug, 1889.

Comments on the Analyses. The infusorial earths are fairly high in water, and this is the main cause of low silica, but, as stated above, their growth and accumulation in water make it unavoidable that more or less clay and other sediments should mingle with them. In these and the other members of the series, it is important to understand that much of the silica is opaline, or amorphous, hydrated silica, and not quartz or chalcedony. Tests of the amounts soluble and insoluble in caustic alkali are usually made to determine the proportions of the two, for, while it is not an accurate separation—quartz and chalcedony being themselves somewhat soluble—it gives an approximate idea. No. 4 is a deposit separated from the geysers by algæ. No. 5 is largely due to sponge spicules, mixed in with chalk, and therefore is high in calcic carbonate.

Mineralogical Composition. Varieties. The mineralogy of the infusorial earths can be stated less definitely than the chemical composition. The individual diatoms are very minute, but the analyses indicate both opaline and chalcedonic silica as being present. In the sinters and cherts, when the latter can be recognized as organic, the same two varieties are recognizable, and with them are varying amounts of calcite. The infusorial earths are fine, powdery deposits, resembling white or gray dried clays, but they lack plasticity and are best recognized with the microscope. Siliceous sinters, often called geyserite, are cellular crusts and fancifully shaped masses that closely resemble calcareous tufas, but that are readily distinguished by their lack of effervescence. Chert is dense, hard and homogeneous, and of white, gray or black color. It readily strikes fire with steel, and when it breaks has a splintery or conchoidal fracture. It is often decomposed to powdery silica on the outside, and in extreme cases may yield rather large deposits of this powder, that are called "tripoli," and are used for various practical purposes. Mention may again be made of the cherts that seem best explained by chemical precipitation.

Metamorphism. The cherts alone of these rocks are of sufficient importance to attract attention in this connection, and their metamorphism is briefly referred to on page 81.

Occurrence. Infusorial earths are abundant near Richmond, Va., and on Chesapeake Bay, at Dunkirk, and Pope's Mills, Md. Beds deposited in evanescent ponds or lakes are also well known in States further north. In the West, the Tertiary strata have yielded them in Nevada. In California and Oregon great areas are reported by Diller. Siliceous sinters produced by algæ are quite extensive in the Yellowstone Park, and similar deposits, perhaps caused by the same agent, are found in many hot spring regions. Sinters chemically precipitated also occur. The most important occurrences of chert are all mentioned together on page 81 .

FERRUGINOUS ORGANIC ROCKS.

It may be questioned if these deserve the dignity of rocks, for they may with great propriety be confined to the minerals distinctively so-called. It will therefore only be mentioned that many have attributed the formation of beds of limonite to the separation of iron hydroxide by low forms of organisms. Even granting this, it is still true that such limonites are insignificant when compared with those that result by purely inorganic reactions in the decay of rocks. Important strata of cherty carbonates of iron are present in the iron mining districts around Lake Superior and have been, no doubt, the principal source of the hematites. Van Hise regards them as probably of organic origin, but the evidence is not decisive and they may be chemical precipitates. Clay-ironstone and black-band ores, that is, argillaceous and bituminous ferrous carbonate, sometimes form continuous beds instead of the usual isolated lenses, but when they do, they are not organic in origin, although decaying organic matter may contribute to preserve the reducing conditions that are necessary to the formation of the ferrous salt.

CARBONACEOUS ORGANIC ROCKS.

When plant tissue accumulates in damp places and under a protecting layer of water that prevents too rapid oxidation, new accessions may more than compensate for loss by decay so that extensive deposits may result. These become progressively rich in carbon by the loss of their other elements and yield beds of considerable geological, but much greater practical importance. The course of the changes and the several stages are indicated in the following table.

	C.	H.	O.	N.	Total.
Woody Tissue	50	6.	43	1.	100.
Peat	59	6.	33.	2.	100.
Lignite	69	5.5	25.	0.8	100.3
Bituminous Coal	82	5.	13.	0.8	100.8
Anthracite	95.	2.5	2.5	trace.	100.

The changes are in the nature of loss of oxygen and hydrogen, and also of carbon, but the decrease of the first two is relatively so much greater, that the carbon actually is enriched. The table is theoretical in that no account is taken of the more or less fortuitous mineral matter that forms the ash together with a small percentage of incombustibles in the vegetable tissue itself. Peat is a more or less incoherent mass of twigs and stems, decidedly carbonized and darkened, but with the original structures, as a general rule, still well preserved and recognizable. By gradual stages it passes into lignite, which is still further compacted, and which exhibits the original structures more faintly. In bituminous coal, they are seldom recognizable, and the aggregate is compact and black. In anthracite the coal is dense, amorphous and lustrous. The oxidation necessary to the latter varieties may have been largely performed before actual burial in other rocks, but the changes are continuous and progressive in all.

Other organic derivatives, such as asphalt, petroleum, etc., are not considered of sufficient abundance to rate as rocks.

Metamorphism. Anthracite is locally produced from bituminous coal, near igneous intrusions and by regional metamorphism, as later explained. The chemical changes are the same as those progressive ones above outlined, but are doubtless more rapidly brought about. Anthracites become graphitic, and, as a theoretical extreme, pass into graphite. Natural cokes are also produced along intruded dikes.

Occurrence. Peat favors cool and moist latitudes in all parts of the world, and is chiefly of fresh water origin. Lignites and coals are best developed in the Carboniferous and Cretaceous strata, and where the former occur in the East and the latter in the West, they often contain coal seams.

IV. PRECIPITATES FROM SOLUTION.

The name of this group indicates the character of the rocks that comprise it. Bearing in mind the condition established at the outset, p. 38, that a rock should form an essential part of the earth, it is evident that water is the only natural solvent abundant enough to yield such rocks, and that only the most widespread compounds that are notably soluble in it, or in its common solutions of other more soluble salts, can meet this requirement. The rocks may be conveniently taken up under the following heads.

1. Precipitates involving the alkaline earths and alkalies. 2. Siliceous precipitates. 3. Ferruginous precipitates.

PRECIPITATES INVOLVING THE ALKALINE EARTHS AND ALKALIES.

The carbonate of lime in stalactites, stalagmites and crusts on the walls and floors of caves in limestone or in the surface deposits from limy springs affords a rock of this character, that is a form of limestone, from pure varieties of which it does not differ in composition, although its banded structure and rings of growth which we may describe by Posepny's useful word "crustification," in a measure distinguish it. Naturally such deposits are often beautifully crystalline, free from admixture except of associated dissolved materials and as a rule purer than sedimentary limestones. They yield our well-known onyx marbles. Some regularly stratified deposits of limestones that are associated with the precipitated rocks next discussed have doubtless originated together with them.

Gypsum and Rock Salt are the chief members of this sub-group. They occur quite invariably in association, and have resulted alike from the evaporation of sea-water and from the drying up of lakes, originally fresh. Both are mixed more or less with dust and other mechanical sediments washed or blown into the evaporating reservoir, or are interbedded with other salts that were present in a minor capacity in the mother liquor, but instances of thick beds, especially of rock salt of surprising purity, are well known. When these attain several hundred or even a thousand feet, it is evident that more than twenty-five times this depth of salt water, on the basis of the known composition of the sea, would have to be evaporated, and this is a practical absurdity even for any conceivable confined body, with occasional renewals from breaches of the barrier. It would be necessary to assume wide stretches of shallows that were practically evaporated to dryness, while at the same time subsidence of the coast was progressing at just about the necessary rate to keep pace with the growth of the salt. The recent explanation, however, advanced as the "Bar theory," by Ochsenius*, clears it up. We need only to assume a relatively deep and nearly land-locked estuary, with a shallow bar between it and the sea. Evaporation continually concentrates the confined salt water and

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* *Zeitschrift f. Praktische Geologie.* May and June, 1893. An excellent abstract by L. L. Hubbard appears in the Geol. of Michigan. V. Part II., p. ix.

especially the portion on the shallow bar. This becoming rich in mineral matter and of high specific gravity, flows inward and down the slope of the bar to the bottom of the estuary. In the course of time, and allowing for the influence of pressure in the depths and of temperature, conditions favorable to precipitation, first, of the insoluble gypsum, later of the more soluble common salt will be reached, and in varying and alternating layers they will be built up indefinitely, or until some upheaval or subsidence alters the relations of the estuary to the sea. More or less anhydrite is also deposited, and is later found in extended cross-sections of salt-bearing strata. The most soluble ingredients, such as KCl, $MgCl_2$, $MgSO_4$, etc., become continually richer in the mother liquor, and unless this is finally evaporated too, they escape and are not found in the series. So far as we know, the Stassfurt district, in Germany, is almost the only place where this escape has been prevented on a large scale, although rock salt is of world-wide distribution.

Gypsum forms at times gray or black earthy beds, that look very much like limestone, but of course do not effervesce. Again, it is in white, cream-colored or deeper-tinted layers, yielding alabaster. Minor portions afford selenite, the clear, transparent variety, and thin coats of native sulphur are seldom lacking. Rock salt forms crystalline beds, often stained red or brown, by iron-oxide. Both gypsum and salt may impregnate associated sediments more or less, yielding gypseous or saline shales and marls. In many localities gypsum deposits have undergone a complex series of chemical changes in the general nature of deoxidization from carbonaceous matter present, so as to yield native sulphur in large amounts.

Metamorphism. None of the above rocks are worthy of mention as regards metamorphism.

Occurrence. In America, gypsum is found especially in the Upper Silurian of New York; the Lower Carboniferous of Michigan and Nova Scotia; the Triassic in the Eastern prairie states, Kansas and Texas; in undetermined Mesozoic in Iowa, and in the Jura-Trias or in undetermined strata in Colorado, Utah and the West. Rock salt occurs in the Upper Silurian of southern New York; in the Triassic of Kansas; in the Quaternary (?) of Petite Anse, La., and at many places of recent geological age in the West.

SILICEOUS PRECIPITATES.

Geyserite.	(a)SiO_2.	(b)SiO_2,	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	K_2O.	Na_2O.	H L
1.	81 95		6.49	tr.	0.56	0.15	0 65	2.56	
Cherts.									
2.	99.46		0.29		0.4	tr.			
3.	3.35	95.78	0.16		tr.	0.01			
4,	4.52	93.65	0.83		0.05	0.01			
5.	98.10		0.24	0.27	0.18			0.23	
6.	94.91		2.85		0.42	tr.			
Sil. Oölite.									
7.	95.83		2.03		1.93	tr.			
					$CaCO_3$.	$MgCO_3$.			
8.	56.50		1.50		16.84	2.60			
9.	3.70		1.42		88.71	8.09			
Cherty iron carbonates.					CaO.	MgO.	FeO.	MnO.	
10.	58.23		0.06	5.01	0.38	9.59	18.41	0.25	
11.	46 46		0.24	0.64	1.87	3.10	26.28	0.21	
12.	28.86		1.29	1.01	0.74	3.64	37.37	0.97	

NOTE. (a)SiO_2 means silica soluble in caustic alkali; (b)SiO_2, silica the same.

1. Geyserite, Splendid Geyser, Yellowstone Park, J. E. Whitfield for W *9th Ann. Rep. Dir. U. S. Geol. Surv.*, 670. 2. Gray unaltered chert, Jopli alysis made by U. S. Geol Surv. Quoted in *Ann. Rep. Geol. Surv. Ark.* 161. 3. White altered chert, Galena, Kan., *Idem.* 4. Unaltered chert, B *Idem.* 5. Decomposed chert, or Tripoli, Seneca, Mo., W. H. Seamon. Quo Hovey, *Amer. Jour. Sci.*, Nov., 1894, 406. 6. Chert, Roaring Springs, Mo., J. D. Robertson, for E. O. Hovey, *Idem.* 7. Siliceous oölite, Center Barbour and Torrey, *Amer. Jour. Sci.*, Sept., 1890, 249. 8. Silica-lime o 9. Lime-silica oölite on same specimen as No. 8, *Idem.* 10, 11. Cherty nates, N. E. Minn., T. M. Chatard, for C. R. Van Hise, *Monograph XIX, Survey*, 192. 12. Cherty iron carbonate, Sunday Lake, Gogebic Range, F. Hillebrand, *Idem.*

Comments on the Analyses. The first seven are high some approximating chemical purity. No. 1 has admi mud thrown out by the geyser from its walls. The fi 2–6 inclusive have but slight amounts of alumina, iron and low percentages of water. Nos. 3 and 4, by the de tions of soluble silica give us some idea of the amoun opaline form that is present. The three analyses 7, 8 a most instructive series, passing as they do from nearly p into a moderately siliceous, magnesian limestone, from first two are thought to have been derived by replacemen 10, 11 and 12 are the curious cherty carbonates of iron fr the Lake Superior iron ores have been formed by subæri Their richness in magnesia as compared with lime is note

Mineralogical Composition. Varieties. Cherts are so exceedingly fine grained that they give no indication of their constituent minerals to the unaided eye. The microscope shows, however, that they are chiefly chalcedony in excessively minute crystals, with which are associated varying amounts of opaline silica, quartz crystals, calcite or dolomite rhombs and dusty particles of iron oxide. In foreign cherts as stated above on p. 74, sponge spicules have been met, but not in the important American varieties. Cherts often have an outer powdery crust due to decomposition, and while as shown by analysis 5, this may not mean any notable chemical change, it may penetrate whole beds and leave only a white incoherent mass called "tripoli," that is used for a polishing powder and for various other purposes. Cherts have spherulites occasionally and are still more often oölitic. The cherty or siliceous rocks of the formations containing the Lake Superior iron ores are mixtures of chalcedonic silica and carbonate of iron in varying proportions, and in their alteration they afford more or less sharply differentiated jaspers and hematites. Three analyses of varying composition are given above, Nos. 10, 11 and 12.

As stated earlier, cherts are intermingled in all proportions with limestones. They are very puzzling problems as regards origin. Where devoid of organisms, the majority of observers regard them as in some way precipitated chemically from sea water, possibly by way of replacement of limestone. Their structure and relations give us few definite clues on which to base a firm conclusion. As earlier stated, others regard them as derived from siliceous remains of organisms, such as sponges, radiolarians and the like, which may have been redissolved and worked over into chalcedony, making them practically precipitates. Cherts are also called hornstone and flint.

Metamorphism. Purely siliceous cherts are unpromising subjects for metamorphism, except as they yield silica in cherty limestones for the production of silicates. The ferruginous cherts of Lake Superior pass into actinolitic and magnetitic slates, a most interesting change, especially in the former case. The lime, magnesia and iron are combined with silica under the metamorphosing influences, so as to yield the actinolite.

Occurrence. The abundance of cherts or related rocks in the region of Lake Superior, either associated with limestone or in the cherty carbonates described above is remarkable. In their economic products, they are the most important strata present. The Siluro-Cambrian limestones are often cherty both east and west, and in the New York and Ohio Devonian, the so-called "Corniferous" limestone was named from its richness in "hornstone." In the Mississippi Valley the lower Carboniferous strata are particularly prolific in cherts.

FERRUGINOUS PRECIPITATES.

Some iron ores doubtless originate in this way, and the processes by which the soluble proto-salts are oxidized and precipitated as the insoluble ferric hydroxide are well understood. But they may be considered rather as minerals than as rocks. The cherty iron carbonates of the preceding section have already been cited, and the clay ironstones and black-band iron ores are omitted from further mention for the same reasons as are the limonites.

THE DETERMINATION OF THE AQUEOUS AND EOLIAN ROCKS.

The members of this series are much easier to recognize than are the igneous. Breccias, conglomerates and sandstones are at once apparent from their fragmental character. Breccias differ from conglomerates in the angular shape of their component fragments. As the sandstones become finer, the argillaceous varieties may be distinguished by the peculiar odor emitted by all clays and clayey rocks when breathed upon. The calcareous sandstones and marls betray themselves by effervescence with acid. All limestones, unless too rich in magnesia, effervesce in cold acid, and the more readily if first scraped up into a little heap of powder with a knife. Dolomites effervesce much less readily, and warm acid may be necessary. Infusorial earth may need the microscope for its certain identification, and then the abundance of the little organisms is very apparent. The cherts are so characteristic in appearance as to admit of little uncertainty, except as compared with the silicified tuffs and excessively fine felsites, called petrosilex, in which case geological surroundings or the microscope are the only resources. The ferruginous rocks, if such be allowed, are self-evident, as are the carbonaceous. Gypsum is easily recognized when in the crystalline form, but when black and earthy, the observer may be forced to determine its lack of effervescence, and to make a sulphur test with the blowpipe. Nevertheless with these rocks as with the igneous, although to a less degree, it is very advisable to gain experience with correctly labeled study collections or with the systematic exhibits of a museum, so that the observer may have a fund of experience back of him from which to draw, and on which to depend when a rock comes up for determination.

For field work and travel, it is well to appreciate that a few dry crystals of citric acid, that can be dissolved in a little water as needed, serve very well for tests of effervescence. They are more safely carried than are liquid mineral acids.

CHAPTER IX.

THE METAMORPHIC ROCKS. INTRODUCTION. THE ROCKS PRODUCED BY CONTACT METAMORPHISM.

The word metamorphism was first introduced into geological literature by Lyell in 1832, and was used to describe the processes by which rocks undergo alteration. It was particularly applied by him to those stratified rocks that, from deep burial in the earth, and from the consequent heat and pressure to which they have been subjected, have assumed structures and textures resembling those of the unstratified primary or plutonic. In this sense it has been generally employed since, and it implies an increase in crystallization, hardness and those attributes which are especially associated with the crystalline schists, as contrasted with the unaltered sediments.

The literal meaning of the phrase "the processes by which rocks undergo alteration" may nevertheless, be somewhat more comprehensive than this, and may be made to include the changes produced by atmospheric agents, which we ordinarily describe by the term weathering, and in the following pages the products of this latter form of alteration will be briefly considered as a third and concluding group.

The metamorphic rocks will therefore be taken up under the following three classes.

I. Rocks reduced by Contact Metamorphism.
II. Rocks produced by Regional Metamorphism.
III. Rocks produced by Atmospheric Weathering.

By contact metamorphism is meant the series of changes that are effected by an igneous intrusion, such as a dike or a laccolite upon the rocks through which it is intruded. These changes are often profound, and are brought about by the heat of the intrusion as well as by vapors and hot solutions which it may likewise give forth. The wall-rock may be itself igneous or sedimentary, or even metamorphic. This form of metamorphism is sometimes called "local" as contrasted with "regional."

By regional metamorphism we describe the series of changes that are produced in the rocks of wide areas or "regions" by deep burial, mountain-making upheavals, and by heat and pressure. Although Lyell had stratified rocks before him as the chief materials on which these agents acted, yet it is well recognized to-day that igneous rocks are no less profoundly affected, and indeed that the results of their alteration may be almost or quite indistinguishable, from those derived from sediments. But there is great uncertainty as to the original condition of many regionally metamorphosed rocks, and although the endeavor has been made in previous pages to throw as much light upon them as possible, by systematically referring to the alteration and metamorphism of simple types, nevertheless, many are obscure, and in their history are involved some of the profoundest problems of geology.

By atmospheric weathering is meant the series of changes wrought in rocks at or near the surface of the earth, by the ordinary atmospheric agents, water, oxygen, carbonic acid and the like. The changes are chiefly in the nature of disintegration, loss of soluble ingredients and decomposition, and in general they produce a marked shrinkage of bulk.

It is important to appreciate that under whatever form the metamorphic rocks are met, they are of necessity alteration products of the two grand divisions over which we have already passed.

GENERALITIES REGARDING CONTACT METAMORPHISM.

Widening observation has shown that contact metamorphism is produced by all varieties of igneous rocks, and that it may be broadly stated to be independent of the kind of rock forming the intrusion. Granites, syenites, nepheline-syenites, diorites, gabbros and even peridotites have in one place and another proved to be efficient agents. Yet the following statements may be said to hold good:

1. Plutonic rocks are more favorable to it than volcanic. This follows because plutonic rocks cool slowly, at considerable depths and stand therefore at high temperatures for long periods next their walls.

2. Magmas rich in mineralizers are much more favorable than are those poor in them. This naturally follows from the powerful influence exerted by escaping vapors. It is tantamount to saying that acidic rocks are in general more efficient than basic ones, because experiment shows, and field observation indicates, that abundant absorbed vapors accompany and facilitate the fusion of the rocks high in silica, whereas basic rocks are much more largely the results of dry fusion. Granites, for instance, are the commonest and most effective agents of contact metamorphism.

3. As regards the walls, sedimentary rocks possess varying susceptibilities. Highly siliceous sandstones and conglomerates, for example, are stubborn subjects, and manifest but slight alteration; but highly aluminous or calcareous beds are favorable to recrystallization because they contain the alumina, iron, lime, magnesia and the alkalies that will combine with silica, under metamorphosing influences, to yield copious contact minerals. Of all rocks, impure limestones yield the most varied and interesting results.

4. With a favorable intrusion, the apparent distance to which the metamorphosing influence penetrates, depends on the angle of emergence of the intrusion. If it comes up at a low angle it may lie but a short distance below the surface for a considerable stretch on one side of the outcrop, so that the metamorphosed area may apparently extend to a great distance, although at no point far from the source of heat. Around a vertical dike the distance would naturally be less. Again, the alterations progress much less readily across the bedding of stratified rocks than along it. Hence, an intrusion that cuts across the bedding produces more widespread effects than does one parallel with it.

5. It is believed by many, especially among English and German observers, that there is very slight migration of material during metamorphism, and therefore that the contact minerals have resulted from the silica and the bases that were practically in the same places before the intrusion as after it. It follows that there has been no chemical introduction or substitution, but only rearrangement of molecules during the process. An analysis, there-

fore, of a reasonably large-sized sample would indicate the composition of the original rock, except so far as water, carbonic acid, and other volatile ingredients have been driven off. From observations upon an intrusion of granite in Westmoreland, England, that cuts a decomposed, basic, amygdaloidal lava, Alfred Harker concluded that the migration had not exceeded one-twentieth of an inch. But among the French much greater power of chemically affecting the walls is attributed to intrusions, and in instances it certainly seems as if, in addition to the fluorine and boron that we all know penetrate into wall rocks during the escape of mineralizers, hydro-fluosilicic acid might impart silica and that some of the bases, and especially the alkalies, might migrate in heated solutions, to a moderate distance.

6. Notwithstanding the truth of the foregoing generalities, it is a curious fact that contact effects are sometimes strangely lacking where we would naturally expect them, and that they are often of varying intensity and irregular distribution, where they do occur. These anomalies can in part be explained by the general principles already cited, of which no doubt the presence or absence of mineralizers, the superheated or relatively cold condition of the intrusion are chief. But every observer of wide experience is sometimes much puzzled by what he meets in Nature.

I. THE ROCKS PRODUCED BY CONTACT METAMORPHISM.

Although the principal results of contact metamorphism are manifested in the walls of the intrusion, the igneous rock is itself influenced. It is therefore necessary to note both the *internal* and the *external* effects, or those upon the intrusion and those upon the walls. The area over which the latter are manifested is often called the aureole, and the concentric rings of decreasing alteration as one passes outward from the intrusion are called zones.

Internal Effects. The igneous rock suffers a relatively rapid loss of heat in its marginal portions as compared with its interior, and as a result it very commonly assumes a porphyritic, felsitic or even, just at the contact, a glassy texture, although it may be granitoid within. Where these textures are well developed the passage from one to the other is extremely gradual, and if the wall rock has been originally a shale or a clay that has been baked to a dense mass, one may need microscopic examination to determine where the intrusion ends and the wall rock begins. The changes in texture in the intrusion are accompanied more or less by changes in chemical composition and in not a few cases progressive analyses have shown the margins to be much more basic than the interior of the intrusion. The chilling of the former has thus produced chemical rearrangements in the magma previous to consolidation.

External Effects. Recalling the statement earlier made that within the limits already set forth the character of the intrusion is immaterial, the most convenient and intelligible method of treatment will be to briefly outline several typical cases wherein the commoner sedimentary rocks are known to have been affected, and then to refer to one or two instances wherein igneous or regionally metamorphic ones have suffered alteration. The same order will be preserved for the sediments as appears under Chapters VII and VIII.

Breccias are too limited in distribution to be a serious factor. Conglomerates and sandstones so generally consist of silica, that they supply but little raw materials of a favorable kind. The small amounts of alumina present may combine with the silica to afford sillimanite (Al_2O_3 ,SiO_2) and stimulated circulations of hot water may cause added deposition of quartz around the grains so as to develop increased hardness.

With shales and clay rocks, even if in the form of slate (see later p. 423) the effects are more pronounced; and around intrusions in them well-marked and well identified zones have been described.

At the contact of the igneous rock with the sediments a breccia or "mixed zone" of intrusive and fragments of wall rock is sometimes, although not always, met. More commonly the shales, slates, clay or their kindred rocks are baked and altered to a dense, flinty product known as a hornfels or hornstone, which latter name in this sense, is however, not to be confused with its use for flints and cherts. It breaks in irregular, angular masses and has a very close resemblance to dense trap. Its mineralogy is, as a general thing, a subject for microscopic study, but it may be said that biotite in small scales is rather the most widespread mineral present, and that andalusite, garnet, cyanite, staurolite, tourmaline, ottrelite, rutile, hornblende, feldspars and other minerals more or less characteristic of such surroundings frequently appear. They may be of considerable size and the prisms of andalusite of the variety chiastolite with the light and dark maltese crosses showing in their cross-sections, are especially frequent. As the contact is left the hornfels often passes into mica schist. Farther out the mineralogical changes become less marked; the andalusite and other crystals are less and less well developed and finally shade into mere dark spots or aggregates of biotite, magnetite and bituminous matter. When even these fade out the unchanged sediment is met. In some localities it has therefore been possible to establish three zones, which are in the reverse order of the above succession, the knotty or spotted slates, the knotty mica schists, and the hornfels, usually with andalusite. By knotty is meant the aspect given by the larger contact minerals in the midst of finer aggregates.

These are the names adopted for a well known contact studied by the eminent German petrographer, Rosenbusch, in the Vosges Mountains. At a famous American locality in the Crawford Notch of the White Mountains, on the slopes of Mt. Willard and not far from the Crawford House, the granite has penetrated an argillitic mica schist or micaceous slate, and the zones are somewhat different. G. W. Hawes in 1881 established the following seven: 1. The argillitic mica schist (chloritic); 2. Mica schist (biotitic); 3. Tourmaline hornstone; 4. Tourmaline veinstone (a small contact band, rich in tourmaline); 5. Mixed schists and granite; 6. Granite porphyry (biotitic); 7. Granite (hornblendic). This is one of the most complete and well-exposed contacts known, and illustrates both external and internal effects.* The succession illustrates the alteration of chlorite to biotite by the granite, and then near the contact the development of tourmaline from the boracic and fluoric emanations which were afforded by it. On the southeast corner of Conanicut Island, in Narragansett Bay, granite has penetrated Carboniferous shales, as described by L. V. Pirsson,† and has baked them to compact hornfels near the contact. Spotted slates are likewise met resembling those described above. Immediately beneath the diabase of the Palisade ridge at Hoboken, N. J., the Triassic shales are baked to a compact

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* Hawes' paper is in the American Journal of Science, January, 1881, p. 21.

† L. V. Pirsson, On the Geology and Petrography of Conanicut Island, R. I. *Amer. Jour. of Sci.*, Nov., 1893, p. 363.

hornsfels with abundant tourmalines, and near Beemerville, N. J.,* a great dike of nepheline-syenite has come up through Ordovician shales and has altered them in places to remarkably dense black hornsfels. Near Crugers, on the Hudson River, mica-diorites have penetrated mica schists and have developed in them a considerable number of characteristic contact minerals, but the changes in the schists are not specially apparent to the eye.† As western and other eastern areas are further studied, no doubt additional cases will be fully described. Many are known and await careful field work.

The contact effects on limestones furnish extremely interesting phenomena and a series of minerals somewhat different from those just described. On account of the general lack of migration of material the elements of the minerals must be present in the unaltered rock. Pure limestones therefore merely crystallize into equally pure marbles. Siliceous and argillaceous ones become thickly charged with biotite, garnet, vesuvianite, scapolite, pyroxenes and amphiboles, tourmaline, spinel, and not a few more. Garnet and vesuvianite are especially characteristic. Good contacts have been met at several American localities. Near St. John, N. B.,‡ granite has penetrated Laurentian limestone and has developed a garnet zone, with more or less pyroxene. Diorites cutting or including limestone in the Cortland series§ have caused the formation of pyroxene, scapolite, hornblende and other minerals.

In the valley extending from Warwick, N. Y., southwest to Sparta, N. J., are most instructive exhibitions, and rich mineral localities are based on them. Granite is the principal intrusive.‖ The western Adirondack region of New York contains many more where gabbro and limestone come together, and where the well known mineral localities occur. C. H. Smyth, Jr., has lately identified their contact nature and will in time describe them. Abroad, the region about Christiania in Norway has proved to be classic ground for these phenomena, and a great contact of diorite on Triassic limestone at Predazzo in the Tyrolese Alps has produced the characteristic zones on a grand scale.

The inclusions of wall rock caught up by an advancing intru-

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* J. F. Kemp. *Trans. New York Acad. Sci.*, xi. p. 60.

† G. H. Williams. *Amer. Jour. Sci.*, Oct., 1888, p. 265.

‡ W. D. Matthew, *Trans. N. Y. Acad. Sci.* XIII, 194.

§ G. H. Williams, *Amer. Jour. Sci.*, Oct., 1888, 267.

‖ J. F. Kemp and Arthur Hollick *Annals N. Y. Acad. Sci.* VII., 644.

sion on its way to the surface are instructive examples, and often are afterwards found entombed in the igneous rock and more or less altered. The lava flows of Vesuvius and the ejected bombs have been of extraordinary interest in this respect. Limestones are frequent among them and they exhibit the same zones as the larger occurrences. Vesuvianite, in fact, received its name from this association.

Of the remaining members of the grand division of the Aqueous rocks, the Carbonaceous are the principal ones deserving mention. Coal seams of the normal bituminous variety have been cut in not a few places by igneous dikes, and display in a marked degree the metamorphosing effect. The volatile hydrocarbons have been driven off and the coal has become an impure coke. The Triassic coal basins of Virginia and North Carolina exhibit many instances where diabase dikes have wrought the change, and in the region of Puget Sound basalt intrusions have effected similar results. In Colorado and New Mexico, the near approach of an igneous sheet has brought about the formation of anthracite, and in fact all grades of coal can be detected from rich bituminous to hard anthracite, according to the nearness of the dike or laccolite.

Reference may also be made to the hills of soft magnetite, near Cornwall, Penn., where a great dike of diabase has altered limonite to this more crystalline and thoroughly anhydrous mineral.

Where intrusions cut other igneous or metamorphic rocks the effects are much less apparent, because the walls are resistant to change, being themselves already crystalline. Around granites, however, even in these conditions, great pegmatite dikes and veins are copiously produced, which seems to be in large part brought about by escaping heated vapors and solutions.

Remarkable cases of contact metamorphism are, however, certainly caused by these last named agents. As rocks they are not specially abundant, although of great scientific interest. Some intrusions have emitted copious emanations of hydrofluoric and boracic acid in conjunction with superheated steam. These vigorous reagents have attacked the wall rocks, when originally formed of crystalline silicates, making them porous and cellular from the destruction of feldspars, and have often caused the crystallization of quartz, tourmaline, topaz, fluoric micas, fluorite, apatite and other characteristic minerals of which cassiterite is of much economic importance. Such metamorphic products when essentially consisting of quartz and mica are called greisen. Tourmaline granites likewise result. It is not to be overlooked, however, that mineralizers have also played a large part in the cases earlier cited, nor should the remark be omitted in conclusion that they and similar agents have been of vast practical importance in the formation of ores.

CHAPTER X.

THE METAMORPHIC ROCKS, CONTINUED. THE ROCKS PRODUCED BY REGIONAL METAMORPHISM. INTRODUCTION. THE GNEISSES AND CRYSTALLINE SCHISTS.

INTRODUCTION.

This subdivision embraces rocks that differ widely among themselves, but that have nevertheless important features in common. The following generalities are applicable in a large way and will serve to emphasize some of the most important points.

1. Regionally metamorphosed rocks are all more or less perfectly crystalline. This is least developed in the slates.

2. They are all more or less decidedly laminated or foliated, although some amphibolites, marbles and serpentines are quite massive. The laminations are due to the arrangement of the constituent minerals, and especially the dark-colored ones, in parallel alignment, so that light and dark layers stand out conspicuously. The terms bedded and stratified should never be applied to them because the banding is largely due to dynamical processes, and has no necessary connection with original sedimentation.

3. They are of ancient geological age or else are in greatly disturbed districts.

It is important in connection with these rocks to distinguish between the effects produced by heat or thermal metamorphism and the effects produced by mechanical forces or dynamic metamorphism. By thermal metamorphism we understand the alterations caused by heat not necessarily accompanied by the mechanical effects such as shearing, crushing and the like, that are comprehended under dynamic metamorphism. Contact metamorphism is of course a variety of the former which, however, is also brought into play alike when rocks are so deeply buried that they come within the sphere of influence of the earth's interior heat, and when from dynamic stresses, they are crushed so that their particles move or slide under great pressure on one another and develop heat by friction. If we imagine for a moment great bodies of rocks which have definite crushing resistances, buried under a load of overlying strata so deep within the earth that their limits of resistance are exceeded, yet so confined that they cannot fly apart, we perceive that they must yield by internal crushing, and if the upheaval of a mountain range eases the strain, that they must flow in a mass. It is to this flow, accompanied by shearing, that the lamination of metamorphic rocks is largely due. Prominent or conspicuous minerals are strung out in parallel alignment, oftentimes with wavy folds and curves, and in the end a foliated or laminated structure is superinduced that suggested the bedding of sediments to the early geologists. It is not to be denied, however, that the laminations do at times correspond to original bedding, because where the contrasts in chemical and mineralogical composition, among the layers are pronounced, they doubtless mark such correspondence, but cases are well known of old conglomerate beds passing directly across the prevailing schistosity of a gneissic district.

During these shearing and flow movements larger crystals, such as the feldspars of porphyries, and the larger uncrushed nuclei of minerals in a general pulp are squeezed and stretched into lenses, and remain like eyes between eyebrows, so that they are called "Augen" from the German word for eyes. Swirling curves and eddies in the laminations are also familiar phenomena and cannot be explained in any other way.

These changes may take place without mineralogical alteration, as when granitoid rocks pass into gneisses that contain simply the crushed fragments of the originals, but as a general thing new combinations are formed in the metamorphosed rock. Pyroxene passes into hornblende; soda-lime feldspars become scapolite or saussurite, and other changes ensue that are best detected with the microscope. Sedimentary rocks suffer entire recrystallization, and sometimes so thoroughly lose their original characters that no clue is afforded as to their history. In regional metamorphism precisely as in the case of the contact metamorphic rocks, it is generally believed that there is no change in composition, except perhaps by the loss of volatilizable ingredients, but only rearrangement of elements. A gross analysis of a reasonably large sample will therefore give a clue to the composition of the original. Heated waters, generally charged with mineral matter and steam have no doubt contributed largely in bringing about the final result.

The Regionally Metamorphosed rocks will be described under the following heads:

1. The Gneisses and Crystalline Schists.
2. The Quartzites and Slates.
3. The Crystalline Limestones and Dolomites: The Ophicalcites, Serpentines and Soapstones.

THE GNEISSES.

Introductory.—Gneiss is an old word, that originated among the early German miners in the Saxon districts. It was especially applied by them to laminated rocks of the mineralogical composition of granite, and in this sense it is quite widely employed to-day. But there are many important gneisses that correspond in mineralogy to the other plutonic rocks, and that are quite as properly designated by this name, so that gneiss has come to be a term that is of loose geological significance very much as is trap, but that is none the less useful for this reason. We may therefore define gneiss as a laminated, metamorphic rock that usually corresponds in mineralogy to some one of the plutonic types. Gneisses differ from schists in the coarseness of the laminations, but as these become finer they pass into schists by insensible gradations. Varieties are sometimes indicated by prefixing the name of the most prominent silicate, usually one of the ferro-magnesian group, thus hornblende-gneiss, biotite-gneiss, pyroxene-gneiss, but we also often speak of quartz-gneiss, orthoclase-gneiss, plagioclase-gneiss, garnet-gneiss and the like.

It is evident at once that the above names are incomplete. Hornblende-gneiss, for instance, does not indicate whether the rock contains orthoclase or plagioclase, quartz or no quartz, and the other ones cited are open to the same or similar objections, and if in the endeavor to embody fuller descriptions we string together the names of all the minerals in the rock, we employ an objectionable and awkward method of coining names. A system has, however, been suggested by C. H. Gordon,* in a recent paper that obviates many of these objections and that is adopted below with

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*Bulletin of the Geological Society of America, VII., 122.

some abbreviations suitable for an elementary book. It is based on the parallelism that exists between the mineralogy of gneisses and that of the massive plutonic rocks, and it avails itself of the short names of the latter, that indicate in each case, a definite combination of minerals to describe the aggregates present in the former. Two sedimentary terms are also added.

Massive Type.	Gneiss of Corresponding Mineralogy.	Sedimentary Type.	Derived Gneiss.
Granite	Granitic Gneiss	Conglomerate	Conglomerate Gneiss
Syenite	Syenitic Gneiss	Sandstone	Quartzite Gneiss
Diorite	Dioritic Gneiss		
Gabbro	Gabbroic Gneiss		
Pyroxenite	Pyroxenitic Gneiss		
Peridotite	Peridotitic Gneiss		

Dr. Gordon also suggests that when gneisses are evidently dynamic derivatives from a massive rock, that this relationship be indicated by using the terms granite-gneiss, syenite-gneiss and so on. If, however, differentiations in the magma before crystallizing have given rise to laminations, that such be distinguished by the adjective gneissoid, as gneissoid gabbros.

Gneisses are occasionally met which do not exactly correspond to any of the above names. Chlorite, for example, is a not uncommon mineral, and while it is evidently an alteration product from pyroxene, hornblende or biotite, the original mineral is not at once apparent, and some such name as chlorite-gneiss must be used. In the same way cordierite-gneiss describes those rare varieties containing cordierite (iolite and dichroite are synonyms of cordierite); sillimanite-gneiss, garnet-gneiss, epidote-gneiss and others convey in their names their characteristic features.

ANALYSES OF GNEISSES.

Chemical analyses often enable us to trace back gneisses to their original rocks, whether igneous or sedimentary, but it requires careful study of correct type analyses and some familiarity with their ranges in composition to do it. So far as their number admits the analyses quoted on earlier pages will be found suggestive:

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	K_2O.	Na_2O.	Loss or H_2O.
1.	76.61	12.45	. .	1.33	0.84	. .	5.42	3.12	0.53
2.	74.95	9.42	7.47	. .	1.65	0.13	2.02	4.05	1.02
3.	73.47	15.07	1.15		4.48	0.12	0.38	5.59	. .
4.	71.46	15.06	. .	2.43	1.40	0.42	5.17	3.23	0.83
5.	69.35	18.83	2.00		5.94	. .	3.78		. .
6.	69.94	14.85	7.62		2.10	0.97	4.33	4.30	0.70
7.	61.96	19.73	. .	4.60	0.35	1.81	2.50	0.79	1.82
8.	57.66	22.83		7.74	1.16	3.56	5.72	0.60	1.50
9.	57.20	19.57	9.52	0.59	5.73	4.40	0.28	2.13	0.88
10.	54.89	13.67	1.35		5.63	4.70	8.34	1.95	2.76

1. Granitic gneiss, west side of Black Hills *40th Par. Survey*, I. p. 110. R. W. Woodward, Anal. 2. Called a dioritic gneiss in reference, contains hornblende, quartz, plagioclase, orthoclase. *Idem.:* R. W. Bunsen, Anal. 3. Conglomerate gneiss, so-called granite; Munson, Mass. Quoted by G. P. Merrill, *Stones for Building and Decoration* p. 418. 4. Granitic gneiss, Iron Mountain, Wyo. R. W. Woodward, Anal. See under No. 1. 5. Dark variety of No. 3. 6. Granite gneiss, derived from a hornblende granite, Trembling Mountain, Quebec, Fundamental Laurentian of Logan. F. D. Adams, *Amer. Jour. Sci.*, July, 1895, p. 67. W. C. Adams, Anal. 7. Quartzitic gneiss, with garnet, sillimanite, graphite and pyrite; St. Jean de Matha, Quebec. *Idem.* N. N. Evans, Anal. 8. Granitic gneiss, probably a metamorphosed clay or slate. Trembling Lake, Quebec. Contains garnets and sillimanite. F. D. Adams, *Amer. Jour. Sci.*, July, 1895, p. 67. W. C. Adams, Anal. 9. Dioritic gneiss, New York City. P. Schweitzer. *Amer. Chemist*, VI. 457, 1876. 10. Gneiss containing malacolite, scapolite, orthoclase, graphite, pyrite. Rawdon, Quebec. See under No. 8.

Comments on the Analyses. Nos. 1, 4 and 6 are clearly derived from granites, presumably by dynamic metamorphism. The analyses correspond closely in their general features with those given on p. 30 except that the Al_2O_3 of No. 1 is a trifle low, and the Fe_2O_3 of No. 6 a trifle high. Nos. 3 and 5 are now known to be metamorphosed Cambrian conglomerate, although so thoroughly recrystallized as to be a well known commercial granite. The conglomerate must have come from granitic or dioritic original rocks. Nos. 7 and 8 correspond to the analyses of slates as noted by F. D. Adams in the original reference (see also under slates, p. 107). No. 10 as noted by Adams is of doubtful interpretation. The high alkalies, lime, magnesia and the moderate silica suggest a basic syenite or trachyte, but the alumina is exceptionally low for these. It may be a tuff or a slightly altered sediment from these originals. No. 2 is a very anomalous rock, and it is difficult to refer it to an original diorite, it is so high in silica and so low in alumina. The iron is very large for so acidic a rock. No. 9 is undoubtedly an altered sediment as indicated by the local geology. Notwithstanding the anomalies of composition, chemical analyses supply one of the surest clues to the geological history of gneisses and it is to be hoped that they will be multiplied in America. At present but few are available, far fewer than of igneous rocks.

Alteration. The alteration of gneisses is similar in all respects to that of their corresponding massive types. The feldspars alter to kaolin, the micas and hornblende to chlorite and the rock softens down to loose aggregates that contribute heavily to the sedimentary rocks.

Distribution. Gneisses are abundant in ancient, geological formations. The early Archean is their especial home, and they form the largest part of its vast areas in Canada, around the Great Lakes, along the Appalachians and in the Cordilleran region. But no single geological age monopolizes them any more than plutonic rocks. There are Cambrian and even Carboniferous gneisses in New England, and dynamic metamorphism may produce them from massive rocks of almost any age. The later geological formations are, however, seldom buried sufficiently deep to be in favorable situations. Much the same holds true of Europe and the rest of the world. The gray and red gneisses of the mining districts about Freiberg, in Saxony, those of the Highlands of Scotland, and in Scandinavia, and the wonderful exhibitions of dynamic metamorphism in the Alps are to be cited as of unusual historic and scientific interest.

Granulite. Granulite is a word that has possessed somewhat contrasted meanings according as it has been used in Germany, France or England. In Germany as first employed it was applied to a finely gneissoid rock that consists chiefly of feldspar, quartz and garnets. These original granulites have other minerals more or less prominently developed, of which cyanite, augite, biotite and hornblende are chief. The texture of the rock is extremely dense, and except for the garnets, cyanite or augite the individual minerals are hardly discernible. Among French and English speaking peoples granulite has been applied to granitic rocks that appear to the eye to be chiefly quartz and feldspar, although the microscope may show muscovite. They are practically binary granites, or rich quartz and feldspar gneisses. The name has also been used for coarse plutonic rocks that have been crushed down by dynamic metamorphism into a finely granular and homogeneous aggregate. But so far as metamorphic rocks have been met in America, cases are very rare which cannot be satisfactory il described without the use of this word, that has been so perverted from its original application as to be practically valueless without an accompanying explanation.

THE CRYSTALLINE SCHISTS.

The crystalline schists have finer laminations than the gneisses, but in other respects the mineralogy is often much the same, and as already stated no very sharp line can be drawn between them. It is important to note that the words "schiste" of the French and "Schiefer" of the Germans are applied to shales, slates and metamorphic schists indiscriminately, but in English schist is only used for metamorphic rocks. The more important schists are broadly classified according to the principal ferro-magnesian silicate that is present into the following three groups under which they will be taken up.

(a) Mica schists.
(b) Hornblende-schists or Amphibolites.
(c) Various Minor Schists.

THE MICA SCHISTS.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.
1.	82.38	11.84	. .	2.28	. .	1.00	0.83	0.38	0.77
2.	79.50	13.36	2.87	. .	0.71	0.95	4.69	0.36	0.78
3.	69.45	14.24	. .	6.54	2.66	1.35	2.52	4.02	0.52
4.	66.21	18.60	. .	5.34	0.44	1.24	3.80	2.16	2.04
5.	62.98	16.88	2.48	5.00	tr.	1.58	7.45	3.02	. .
6.	61.57	19.53	5.44	2.61	tr.	1.90	2.14	3.48	. .
7.	60.49	19.35	0.48	5.98	1.08	2.89	3.44	2.55	3.66
8.	57.67	17.92	. .	9.00	3.19	3.29	3.86	1.09	3.19
9.	55.12	24.32	6.13	4.99	tr.	tr.	2.83	2.71	. .
10.	49.00	23.65	8.07	. .	0.63	0.94	9.11	1.75	3.41

1. Mica-schist, rich in quartz, Monte Rosa, Switzerland., Zulkowsky, *Sitz. Wiener Akad.* XXXIV., 41, 1895. 2. Mica-schist, with quartz and green mica Zermatt. Switzerland. Bunsen in *Roth's Tabellen*, 1862. 3. Garnetiferous mica schist with feldspar, Brixen. Tyrol. Schönfeld and Roscoe, *Ann. der. Chem. u. Phar.*, XCI., 1854. 305. 4. Mica-schist near Meissen, Saxony, Hilger quoted in *Roth's Tabellen*, 1879. 5. Mica-schist, Crugers, N. Y., contains quartz, orthoclase, biotite, muscovite, little oligoclase, etc. F. L. Nason for G. H. Williams, *Amer. Jour. Sci.*, Oct., 1888. 259. 6. Crumpled garnetiferous mica-schists. *Idem.* 7. Argillitic mica-schist, G. W. Hawes, *Geology of New Hampshire, Part III.* 219. 8. Mica-schist near Messina, Sicily, Ricciardi. Quoted in *Roth's Tabellen*, 1884, p. ix. 9. Staurolite mica-schist, with biotite, muscovite, quartz, sillimanite, garnet. See under No. 6. 10. Sericite schist, Wisconsin, *Wis. Geol. Surv.*, I. 304.

Comments on the Analyses. Like the majority of gneisses the mica-schists are more or less closely parallel with the granites in chemical composition because the constituent minerals are so largely the same in both. But where they have been formed from metamorphosed sediments such as shales, clays, and the like, the alkalies are often lower than is the case with siliceous igneous rocks, and, what is still more characteristic of sediments as contrasted with highly siliceous igneous rocks, the magnesia is in excess of the lime. A comparison of the above analyses with those of the rhyolites, trachytes, granites and syenites earlier given will forcibly bring this out. The local geology as well as the analyses, indicate that there is little doubt that Nos. 5, 6, 7 and 9 are altered sediments, and the presumption is strong that most of the others are also.

Mineralogical Composition. Varieties. The most prominent and abundant minerals in the mica-schists are quartz, muscovite and biotite. While they are more or less interleaved together, yet close examination of the coarser varieties shows that they are in layers irregularly parallel and to a large extent distinct. The minerals are in all degrees of relative abundance, quartz sometimes largely predominating and marking a passage to the quartzites, while again the micas may be in great excess. Both muscovite and biotite are met, the former being, perhaps, rather the more abundant. With these chief minerals are almost always associated very considerable amounts of feldspar, both orthoclase and plagioclase, and variable proportions of garnet, staurolite, cyanite, sillimanite, tourmaline, apatite, pyrite and magnetite.

The garnet and staurolite may exhibit surprisingly well developed crystals and illustrate the extraordinary power of certain compounds to crystallize under circumstances apparently ill-adapted to their perfect development.

Mica-schists embrace a series from rather coarsely crystalline varieties to others that are excessively fine-grained and that are near relatives of the slates. The minerals of the latter may be of microscopic dimensions, and only the aggregate of shining scales reveals them as mica. Such aggregates, of a silvery white color but of composition essentially the same as normal muscovite, are called sericite, and the corresponding schists, sericite-schists. A related soda-mica (muscovite and its relatives are potash micas) is called paragonite. Hydromica is a name applied many years ago by Dana to sericite, paragonite, and perhaps others resembling them, so that for these finely micaceous schists, especially in our eastern states, hydromica schist is a field name that is largely used in practice and in geological reports. These fine-grained mica-schists that approximate slates are also made a special group by many, under the name phyllite, a very useful term and one to be strongly commended. Mica-schists are also met that are high in lime and that mark transitions to the crystalline limestones. The abundance of calcite or dolomite betrays them, and to such the names calcareous schist or calc-schist are applied.

Mica-schists result from the thorough metamorphism or recrystallization of sandstones, shales and clays, and also from the crushing and excessive shearing of igneous rocks, granitoid and porphyritic alike. A possible origin from ancient volcanic tuffs is always to be considered in the study of a district, but the questions of origin are obscure and are subjects for thorough chemical and microscopical investigation.

Alteration. The mica-schists are rather resistant to alteration and often appear on mountain tops. When alteration does prevail, they soften to masses of quartz sand, chlorite scales and kaolin.

Distribution. The mica-schists form the country rock over vast areas in New England and to the south along the eastern Appalachians. Although long regarded as of uncertain or obscure geological relations they are now recognized in large part at least as metamorphosed Cambrian and Ordovician shales or related sediments. Around Lake Superior and in the regionally metamorphosed areas of the West they are not lacking.

THE HORNBLENDE SCHISTS OR AMPHIBOLITES.

Introductory.—Under dynamic metamorphism the basic igneous rocks whose chief bisilicate is pyroxene, pass very readily into hornblendic rocks, with a greater or less development of schistosity. On account of the prevailing parallel arrangement of the prismatic crystals of hornblende, schistosity is seldom entirely lacking, but where less distinct the name amphibolite has proved to be a useful alternative, and indeed is of wide general application. Sedimentary rocks are also known in rarer instances to yield similar results.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.
1.	52.39	16.13	1.64	1.44	8.76	4.70	1.42	2.59	0.17
2.	50.44	8.18	1.06	6.28	11.55	17.63	0.50	2.98	0.98
3.	49.19	18.71	5.03	4.04	5.92	7.98	0.77	1.44	5.05
4.	46.31	11.14		21.69	9.68	tr.		6.91	4.44
5.	44.49	16.37	5.07	5.50	7.94	7.50	0.56	2.59	4.99

1. Hornblende-schist, Grand Rapids, Wis. *Geology of Wis.* IV. 629. Also, Fe in pyrite, 0.34; S, 0.39; P_2O_5, 0.28 Ca in apatite 0.815. 2. Pseudo-diorite of Becker, Knoxville, Calif. *Monograph XIII. U. S. Geol. Surv. 101*, W. H. Melville, Anal. Also, MnO 0.213, Cr_2O_3 0.480. 3. Hornblende-schist derived from gabbro, Lower Quinnesec Basin, Wis. R. B. Riggs for G. H. Williams, *Bull. 62 U. S. Geol. Surv.* p. 89. Also CO_2 1.82. 4. Hornblende-schist near Cleveland Mine, Mich. Foster and Whitney *Rept. on the Iron Lands of Lake Superior.* p. 92. 5. Hornblende-schist, Lower Quinnesec Falls, Wis. R. B. Riggs for G. H. Williams, *Bull. 62. U. S. Geol. Surv.* p. 91. Also CO_2 5.38.

Comments on the Analyses. The analyses indicate basic rocks, of decidedly variable composition. Nos. 3 and 5 are certainly sheared igneous rocks. No. 2 is regarded by Becker as a metamorphosed sediment. It is quite different from the others in its low alumina, and its great excess of magnesia over lime. No. 1 appears to be an altered igneous rock and No. 4 is probably the same. Aside from exhibiting the composition of these rocks, the analyses are interesting when compared with those of the basic diorites (p. 47) and the gabbros and pyroxenites (p. 49.)

Mineralogical Composition. Varieties. The most abundant mineral in these rocks is naturally hornblende. With it are associated oftentimes biotite, augite, plagioclase, garnet, magnetite, pyrite and pyrrhotite; but quartz except as forming veinlets is not often met nor is it to be expected in such basic rocks. The commonest variety of hornblende is black to the eye but is green in thin section. It forms prismatic crystals from moderately coarse to microscopically fine. The prisms are interlaced so as to make a very tough aggregate and one that breaks with difficulty under the hammer. Light green actinolite may also form schists. Black scales of biotite appear interlaminated with the hornblende. The augite is not readily distinguished from the hornblende with the eye alone. It is in large degree the remnants of original pyroxenes that have partially passed into hornblende during the metamorphic process. The plagioclase also represents to a great extent the feldspar that was in the original gabbro or other igneous rock from which the amphibolite has been derived. The plagioclase is often replaced by secondary products, such as epidote, calcite, scapolite and others, which together make up the aggregate formerly called saussurite and regarded as an individual mineral. The minor accessories magnetite, pyrite, pyrrhotite and garnet deserve no special mention. Except magnetite, which never fails, they are of more or less irregular occurrence.

Alteration. The hornblende passes readily into chlorite and softens to a scaly mass with the separation of much limonite that yields a characteristic, rusty outcrop. If any pyrite or pyrrhotite is present it greatly expedites the alteration by its contribution of sulphuric acid. The feldspars yield calcite and kaolin and the whole mass becomes a rusty clay or soil.

Occurrence. The hornblende-schists constitute individual belts in schistose regions in the midst of other metamorphic rocks and also great areas by themselves. Dikes and sheets of diabase and plutonic masses of gabbro in districts that have been subjected to violent dynamic upheavals readily pass into them. The same areas in the Eastern States that were cited under gabbro contain them, and they are minor members in the schistose districts of New England. Around Lake Superior they form a most important part of the geology of the iron ore regions, and in the Black Hills, the Rocky Mountains and the ranges of California they are often met.

Various Minor Schists.

Under this collective term are assembled a series of minor rocks, no one of which compares in importance with the schists already mentioned, but which may be met as subordinate members of metamorphic districts. There are also others in considerably variety which are esteemed too unimportant for an elementary book.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.
Chlorite schist.									
1.	49.18	15.09	12.90		10.59	5.22	1.51	3.64	1.87
2.	47.10	2.14	44.33		0.36	0.13			5.19
Talc schist.									
3.	58.66	9.26	4.42		0.94	22.78			4.09
4.	50.81	4.53	3.52	4.26		31.55			4.42
Epidote schist.									
5.	41.28	18.48	9.44	8.20	7.04	7.48	2.21	3.52	2.74
Eclogite.									
6.	48.89	14.46	2.00	7.15	13.76	12.21	0.17	1.75	.40
Glaucophane schist.									
7.	47.84	16.88	4.99	5.56	11.15	7.89	0.46	3.20	1.98

1. Chlorite schist, Klippe, Sweden, Cronqvist for Törnebohn. Quoted by Roth, *Gesteinsanalysen*, 1884, p. VIII. 2. Chlorite schist, Foster Mine, Mich., C. F. Chandler, *Geol. of Mich.* I, 91. 3. Talc schist, Fahlun, Sweden, Uhde quoted by Roth, *Gesteinsanalysen*, 1861, 56. 4. Talc schist, Gastein, Austria, R. Richter, *Idem.* 5. Epidote schist from diabase, South Mountain, Pa., C. H. Henderson, *Trans. Amer. Inst. Min. Eng.*, XII, 82. 6. Eclogite, Altenburg, Austria, Schuster *Tscher. Mitt*, 1878, 368. 7. Glaucophane schist, Monte Diablo, Calif., W. H. Melville, *Bull. Geol. Amer.* II, 413.

Comments on the Analyses. These analyses are too variable to admit of much in the way of comparative remarks, for the rocks are so totally unlike. No. 1 suggests an original diabase or some such rock. No. 2 is abnormally rich in iron, doubtless in large part from magnetite or hematite. The high magnesia in Nos. 3 and 4 is characteristic and indicates their close relations with serpentines. No. 5 is an altered diabase. No. 6 is of a rock variable in its mineralogy and obscure in its history. No. 7 is practically a hornblende-schist with glaucophane, an amphibole that is high in soda, instead of common hornblende.

Mineralogical Composition, Varieties. The chlorite schists are marked by the presence of this green micaceous mineral in large amount. More or less quartz is also generally present, and not infrequently plagioclase, talc, epidote and magnetite. The schistose texture is pronounced. The chlorite-schists are manifestly alteration products from some rock, with abundant anhydrous, iron-alumina silicates. Hornblende-schists, presumably from basic igneous rocks are the general source. Certain chlorite-schists are often called "green schists."

Talc-schists are characterized by sufficient talc to make this mineral prominent and in addition they have quartz as the next most abundant constituent. Feldspar may at times be noted, and some micaceous mineral is not rare. Care is necessary not to confuse fine scales of the last named with talc itself. Various accessory minerals likewise occur, and the magnesian carbonates, dolomite and magnesite are often present. Obviously the talc-schists have resulted from the alteration of some rock with one or more anhydrous magnesian silicates that lacked iron. Tremolite and enstatite are the most available, but the original sources of these are often obscure. Siliceous dolomites or intrusive pyroxenites at once suggest themselves, but the iron must of necessity have been low, so as not to yield serpentines.

Epidote-schists result when the ferro-magnesian silicates plagioclases are so favorably situated with reference to each other as to establish mutual reactions. They especially arise as phases in the metamorphism of pyroxenic or hornblendic rocks, such as diabase, hornblende-schists and the like. Eclogite is a rock scarcely known in America, having, as yet, only been noted near the Washington Mine, Marquette District, Mich. (Geol. of Wis., III, 649). It is a well recognized variety, however, in Europe. It consists of bright green amphiboles and pyroxene, of garnet and of a variety of minor minerals. In ordinary determination it would not be distinguished from a garnetiferous, actinolite schist. Glaucophane is a blue soda amphibole that is rare in America, except in the coast range of California, where it characterizes certain important schists. The rocks have a pronounced blue shade, and contain in addition quartz and feldspar. In California they certainly are altered shales. Graphite appears quite commonly as a characteristic mineral of certain schists, and may justify the use of the name graphite schist. More or less mica, and always quartz and feldspar are associated.

Distribution.—Chlorite-schist and talc-schist are not uncommon members of our larger metamorphic series, especially along the Appalachians, in New England and around Lake Superior. Epidote-schist is less common in the same relations. The occurrence of eclogite and glaucophane-schist has already been cited. Graphite-schist is not infrequent in the metamorphosed Paleozoic strata of the East.

CHAPTER XI.

THE METAMORPHIC ROCKS, CONTINUED. THE ROCKS PRODUCED BY REGIONAL METAMORPHISM. THE QUARTZITES AND SLATES. THE CRYSTALLINE LIMESTONES AND DOLOMITES, OPHICALCITES, SERPENTINES AND SOAPSTONES.

THE QUARTZITES.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	Sp. Gr.
1.	97.1	1.39	1.25		0.18	0.13				
2.	96.44	1.74		0.33	0.17	0.22	0.13	0.19	0.90	
3.	84.52	12.33		2.12	0.31	tr.	0.11	0.34	2.31	2.74

1. Quartzite, Chickies Station, Penn.,* *Penn. Geol. Surv. Rep. M.* p. 91. 2. Sandstone partly altered to Quartzite, Quarry Mtn. Ark., R. N. Brackett for L. S. Grisswold, *Geol. of Ark.* 1890, III, 140, 161. 3. Quartzite, Pipestone, Minn. W. A. Noyes in *Minn. Geol. Surv.* I, 198.

Comments on the Analyses. There is no essential difference in the analyses of quartzites and sandstones, as the few quoted above will show, but doubtless the resulting quartzite is somewhat richer in silica than the original sandstone. Comparatively few analyses of quartzites have been made in America.

Mineralogical Composition, Varieties. The quartzites are metamorphosed sandstones, and differ from the latter principally in their greater hardness, and to a certain extent in their fairly pronounced crystalline character. These qualities are due to the presence of an abundant siliceous cement that is crystalline quartz, and that is often deposited around the grains of quartz of the original sandstone, so as to continue their physical and optical properties. The original grains have, therefore, had the power of controlling the

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*By a mistake in copying, somewhat justified by the arrangement in Report M., an analysis of a damourite slate was quoted on p. 66, No. 1, as this quartzite. The error is noted in the Errata, at the opening of the book.

orientation of the molecules of the new silica as it crystallized. When the original sandstone has been argillaceous the resulting quartzite contains mica and especially muscovite, and with increase of the mica, such quartzites pass through the intermediate varieties of quartz-schist into mica-schists. A very curious and more or less micaceous variety is the so-called flexible sandstone or itacolumite, whose grains have the power of slight movement on one another from their loosely interlocked arrangement so that thin slabs may be bent through a considerable arc. Quartzites also result from pebbly sandstones and conglomerates, and the pebbles of these latter are often flattened by the dynamic movements with which the metamorphism is at times associated. There is no sharp line of demarcation between quartzites and sandstones, and while the extremes of soft sandstones and hard quartzites are entirely different, the determination of intermediate varieties is more or less arbitrary.

Alteration. Quartzites sometimes soften to sand on their outcrops, and in the process, almost the last vestiges of alumina or lime may be removed. In this way the sands in analysis No. 1, p. 63, were formed. In general, however, they are excessively resistant rocks, and tend to form prominent ledges.

Distribution. Quartzites occur in almost all series of metamorphosed sediments, and as these are best developed in the later Archean, (Huronian, Algonkian) strata, they especially characterize them. In the metamorphic belt in New England and down to the southern Appalachians, they are frequent, as well as in the Huronian, around Lake Superior and Lake Huron and in the similar areas of the West.

THE SLATES.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.
1.	66.45	13.38	1.71	1.41	2.86.	6.28	0.05	0.90	4.03
2.	66.00		24.60		tr.	tr.	3.67	2.22	3.00
3.	65.85	16.65	. .	53.1	0.59	2.95	3.74	1.31	3.10
4.	64.57	17.30	7.46		1.16	2.60	1.99	. .	4.62
5.	63.31	16.16	3.79		0.15	4.44	7.56	1.54	2.65
6.	60.50	19.70		7.83	1.12	2.20	3.18	2.20	3.30
7.	60.32	23.10		7.05	. .	0.87	3.83	0.49	4.08
8.	57.00	20.10		10.98	1.23	3.39	1.73	1.30	4.40
9.	55.88	21.85		9.03	0.16	1.49	3.64	0.46	3.39
10.	54.80	23.15		9.58	1.06	2.16	3.37	2.22	3.90

1. Slate Llanberis, Wales. Quoted by G. P. Merrill, *Stones for Building and Decoration*, p. 421, also MnO, 0.91, CO_2, 1.30. 2. Slate, Etchemin Riv. N. B., T. S. Hunt, *Phil. Mag.* (4) VII, 237, 1854. 3. Roofing slate, Westbury, Can., *Idem.* 4. Roofing slate, Lehesten, Germany. Frick, quoted by Roth, *Gesteinsanalysen*, 1861, p. 57. 5. Damourite slate, Hensingerville, Pa., *Geol. of Penn. Rep. M.* 91. Note.—This analysis was misquoted as an argillaceous sandstone on p. 66, to which, however, it corresponds quite well in composition. 6. Roofing slate, Wales, T. S. Hunt as under No. 2. 7. Slate, Lancaster Co., Penn., also FeS_2 0.09. See under No. 1, 8, Roofing slate, Angers, France, T. S. Hunt, as under No. 2. 9. Blue-black carbonaceous slate, Peach Bottom slate, York Co., Penn., also MnO., 0.586, CoO. tr. C. 1.974, FeS_2, 0.51, SO_3, 0.022. See under No. 1, 10, Roofing slate, Kingsey, Quebec, T. S. Hunt, as under No. 2.

Comments on the Analyses. These analyses are especially significant when compared with those of the shales and clays, p. 66, and with those of the mica-schists, p. 99, with which latter they are closely parallel. Two features at once impress the observer, the excess of magnesia over lime, and the excess of potash over soda. The former stamps their origin as from sediments rather than from igneous rocks of these percentages in silica, because this relative excess of magnesia as noted under the mica-schists is rather characteristic of sediments.

Mineralogical Composition. Varieties. As the sandstones during metamorphism pass into quartzites, so the shales and clays become slates, when not so thoroughly recrystallized as to yield mica-schists or phyllites. The more sandy shales afford varieties that break irregularly and that lack homogeneity, but tough and even slates result from homogeneous clays and are among the most remarkable of rocks. The distinctive feature of slates as against shales is the possession of a new cleavage that may lie at any angle with the original bedding of the rock, and that has no definite relation to it. The cleavage has been developed by dynamic strains that have, beyond question, involved a shearing stress and, some differential movement among the layers, though it may have been microscopic. As a matter of observation the component grains of slates have become flattened and lie parallel with the new cleavage, and any mica flakes or hornblende needles that may be present lie along it.

Various explanations have been advanced for slaty cleavage, and its artificial production in different substances has occupied severa investigators. Based principally upon experiments performed b Professor John Tyndall, over forty years ago, it has been usuall referred to a compressive force at right angles to its plane. Tynda subjected blocks of wax to pressure, using wet glass plates as his buttress of resistance. The blocks were of course greatly reduced in thickness and were force to spread or bulge laterally. Shortly afterward H. C. Sorby, partly on the basis of the flattening of the component grains, and the alignment of mica scales, explained the cleavage as due to planes of weakness caused by this new arrangement. Recently, G. F. Becker of the U. S. Geological Survey has repeated the experiments of Tyndall with modifications. So long as the resisting glass plates were wet with water the slaty cleavage was developed, but when they were smeared with a heavy lubricating oil, although there was lateral expansion during compression, no bulging took place and no cleavage was developed. Manifestly therefore the frictional drag of the plates enters into the problem, and although the resolution of the forces involved is somewhat complex, a shearing stress results that is a strong factor in producing the cleavage.* In the case of the large beds or strata which are metamorphosed into slate in Nature, the case is even less simple, and the contrasts in rigidity, between the beds that yield slates and their enclosing strata, are less pronounced than in the experiment, but there is little doubt that the compression and lateral flow with their attendant strains, occasion the cleavage, and that the flattening of the grains and alignment of the scaly minerals are attendant phenomena. All slates have cross-cleavages, also, more or less well developed, and one of these may even be perfect enough to cause the slate to break into small prisms available for slate pencils, for which in earlier years they were employed. All slate-quarries also show curly slates, where quartz-veins or sandy and harder streaks in the original sediment have caused imperfections in the cleavage. It has also been noted that in some quarries the available plates appear to become thicker in depth, as if the surface weathering had been a factor in developing the cleavages. Though commonly drab to black, they may be red, green or purple.

Slates pass by all intermediate gradations into phyllites and mica-schists. The word slate is also loosely used for shales, that have never had any secondary cleavage induced in them, and this is especially true of the black, bituminous shales that occur with coal seams, but in strict, geological use, the new cleavage and metamorphism should be an essential of a true slate.

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*G. F. Becker, Finite homogeneous Strain, Flow and Rupture in Rocks, *Bull. Geol. Soc. Amer.* IV, 82, 1893.

Alteration. Slates are exceedingly resistant as is shown by their use in thin slabs for roofs, and they often constitute prominent ledges or even peaks. They soften down to a clay in the last stages of alteration, but always on the outcrop are more tender than in depth, so that much dead work is unavoidable in opening quarries.

Distribution. Our most prominent slates are Cambrian or Ordovician in age. Along the Green Mountains and especially in northern Vermont they are strongly developed. Again in eastern Pennsylvania, in Virginia and in Georgia they are met in great areas. On the south shore of Lake Superior merchantable grades have been somewhat developed. Along the western slopes of the Sierra Nevada Mountains they are a very important rock.

THE CRYSTALLINE LIMESTONES AND DOLOMITES.

	$CaCO_3$.	$MgCO_3$.	SiO_2.	Al_2O_3.	Fe_2O_3, FeO.	Insol.	Loss or H_2O.
1.	99.51					0.29	0.20
2.	99.24	0.28					
3.	98.43	0.30		0.31		0.38	0.15
4.	98.21	2.35		0.15		0.35	
5.	98.00					0.57	1.63
6.	96.82	1.89		0.10		2.12	
7.	92.42	6.47		0.35		0.95	
8.	70.1	25.40				2.40	
9.	54.62	45.04	0.10	0.7			
10.	54.25	44.45				0.60	

1. Statuary Marble, Brandon, Vt. Quoted by G. P. Merrill, *Stones for Building and Decoration*, 417. 2. Marble, Carrara, Italy, *Idem.* 3. Marble, Knoxville, Tenn., *Idem*, also S, 0.014, Organic Matter 0.068. 4. Coarse-grained black and white mottled Marble, Pickens Co., Ga., locally called Creole; *Geol. Surv. Ga., Bulletin* I, 87. 5. White Marble, Rutland, Vt., see under No. 1. 6. Coarsely crystalline white Marble, Cherokee Quarry, Pickens Co., Ga., see under No. 4. 7. White Crystalline Limestone, Franklin Furnace, N. J., Geo. C. Stone, unpublished. 8. Crystalline Magnesian Limestone, Tuckahoe, N. Y., H. L. Bowker for Lime Co. 9. Crystalline Dolomite, so-called "Snowflake Marble," XVI. *Ann. Rep. Div. U. S. Geol. Survey*, Article "Stone," Reprint p. 41. 10. Crystalline Dolomite, white Marble, Inyo Co., Calif., *Ann. Rep. Calif. State Mineralogist, 218.*

Comments on the Analyses. The analyses do not differ essentially from those of unaltered limestones except so far as the ones in the table are purer carbonates of lime and magnesia. The available analyses are of merchantable marbles, and in the nature of the case these are derived from very pure sedimentary limestones. They are interesting as illustrating the series from almost chemically pure carbonate of lime to one in which the carbonate of magnesia reaches the values of typical dolomite. Comparison with the analyses of limestones earlier given, on p. 70, is recommended. It will be seen that in this case there is apparently no change in gross composition from metamorphism, but of course the relations of the silica and the bases are different. In the sedimentary limestones the silica is largely in the form of quartz and in combination with alumina forming hydrated silicates, such as kaolin. In the crystalline limestones it is largely in silicates of lime, magnesia and alumina, such as tremolite, pyroxene, phlogopite, etc., minerals whose formation has been one of the results of metamorphism. The percentages in the insoluble column do not therefore indicate pure silica. There may be even microscopic barite crystals present.

Mineralogical Composition. Varieties. The crystalline limestones and dolomites are metamorphosed forms of the sedimentary varieties earlier described. The change involved is, as the name implies, one of crystallization. Fossils, and to a large degree bedding planes, are destroyed and a more massive aggregate of calcite or dolomite crystals results. Such carbonaceous material as was originally present usually affords streaks of graphite which occasion dark veinings. They bring out the brecciation or flow-lines induced by the pressure from the mountain-making upheavals usually attendant on the metamorphism. Other bituminous or ferruginous matter may yield pronounced colors of many hues.

If the original limestone has been an impure variety and has contained silica, alumina and iron oxides, as illustrated by the analyses on p. 70, these components have furnished the necessary materials for the various silicates that the metamorphism has caused to form. Tremolite is a common result, light-colored pyroxenes are not infrequent, and phlogopite and other micaceous minerals are the most abundant of all. Large quarries always show borders or streaks that are characterized by these minerals, and where the original limestone passed into shales or sandstones at its upper and under surface, these micaceous varieties are almost always met. For ornamental purposes the included silicates, being except in the case of micas, of greater hardness than the calcite, serve to mar the stone.

Crystalline limestones form more or less extensive strata in the midst of other metamorphic rocks. Slates, phyllites, mica-schists and quartzites are their most common associates. The dolomites may have formed in many cases from pure calcareous limestones by the infiltration of magnesian solutions, and by an exchange of a portion of the magnesia for a portion of the lime, as earlier referred to on page 71, but so many unaltered limestones are high in magnesia, that the change is not a necessary attendant of metamorphism.

Alteration. Crystalline limestones are soluble rocks and weather with comparative facility. Where they occur in metamorphic belts they are invariably in the valleys, and are potent factors in determining the direction of the drainage lines. Where exposed for long periods they afford a coarse, crumbling sand or gravel, that is much used for roads in the borders of the Adirondacks and in western New England. The final stage is a mantle of residual clay from which the calcareous material has been largely leached.

Occurrence. The crystalline limestones are frequent in our metamorphic districts. In the Appalachian belt they are of great areal and economic importance, and are largely quarried in Vermont, Massachusetts, New York, Pennsylvania and Georgia. In western Colorado they are strongly developed, and in the Sierras of California the same is true, Inyo County being a rather large producer of marble. The foreign mountainous and metamorphic districts exhibit enormous exposures. The great series of ranges that begin in the Pyrenees and extend through the Alps and the Carpathians to the Himalayas, have many famous quarries and ledges. The region of the "Dolomites" in the Tyrolese Alps is a district of especial richness. The Carrara marble of the Appenines, the Pentelic of Greece and the colored varieties from Northern Africa, indicate their presence in those regions.

THE OPHICALCITES, SERPENTINES AND SOAPSTONES.

Ophicalc.	$CaCO_3$.	$MgCO_3$.	$FeCO_3$.	SiO_2.	MgO.	H_2O.	FeO.	Al_2O_3.	
1.	57.37	9.64	0.74	13.18	10.29	4.06	3.57	0.85	
2.	23.85	22.28	1.97	22.42	18.74	6.43	4.30		
3.	7.65	10.98	1.78	36.53	28.08	8.63	6.49		
Serp.	SiO_2.	MgO.	H_2O.	Al_2O_3.	Cr_2O_3	Fe_2O_3.	FeO.	NiO.	CaC[illegible].
4.	44.14	42.97	12.89						
5.	43.87	38.62	9.55	0.31			7.17	0.27	0.0[illegible]
6.	42.52	42.16	14.22			1.96			
7.	41.54	40.42	14.17	2.48			1.37	0.04	
8.	40.67	32.61	12.77	5.13			8.12		
9.	40.06	39.02	12.10	1.37	0.20		3.43	0.71	
10.	36.95	33.07	10.40			16.50			
11.	34.84	30.74	17.39	0.42	0.68	6.08	1.85	tr.	7.02
Soapst.									MnO.
12.	64.44	33.19	0.34	0.48			1.39	0.23	
13.	62.10	32.40	2.05				1.30		2.15
14.	62.00	33.1	4.9						

1. Ophicalcite, Oxford, Quebec, T. S. Hunt, *Amer. Jour. Sci.*, March, 1858, 220. The analysis as cited is assembled from several partial analyses. 2. Ophicalcite, Brompton Lake, Quebec, *Idem*, p. 221. Original results recast as in No. 1. 3. Ophicalcite, Brompton Lake, Quebec, *Idem*, p. 222. Recast as before. 4. Theoretical serpentine, $H_4Mg_3SiO_9$. 5. Massive serpentine, Webster, N. C., F. A. Genth, *Amer. Jour. Sc.*, II, xxxiii, 201. 6. Massive serpentine, Montville, N. J., E. A. Manice, *Dana's Mineralogy*, 1877, 467. 7. Serpentine, a metamorphosed sandstone, New Idria, Calif., W. H. Melville for G. H. Becker, in *Monograph, XIII., U. S. Geol. Surv.*, 110. 8. Serpentine, decomposed peridotite, Syracuse, N. Y., T. S. Hunt, *Amer. Jour. Sci.*, Sept., 1858, 237. 9. Serpentine, Dublin, Harford Co., Md. Quoted by G. P. Merrill, *Stones for Building and Decoration*, 414. 10. Serpentine from peridotite, Presq' Isle, Mich., J. D. Whitney, *Amer. Jour. Sci.*, II., xxviii., 18, also Na_2O, 0.97. 11. Serpentine, from peridotite, Monte Diablo, Calif., W. H. Melville, Bull. Geol. Soc. Amer., II., 408, also Na_2O, 0.42, K_2O, 0.07. 12. Soapstone, Webster, Jackson Co., N. C., F. A. Genth, *Minerals of North Carolina*, p. 61. 13. Talc, Gouverneur, N. Y., Analysis quoted by C. H. Smyth, Jr., *Sch. of Mines Quarterly*, July, 1896, p. 340. 14. Theoretical talc, 6MgO, $5SiO_2$, $2H_2O$.

Comments on the Analyses. The ophicalcites mark a passage from the dolomites to the serpentines. They are practically crystalline magnesian limestones or dolomites, that are mottled with inclusions of serpentine in varying amounts. The analyses begin with one that is over half calcite and over two-thirds calcite and dolomite. The ratios of the remaining oxides are just about those required by serpentine. In the second the amount of serpentine has much increased and in the third the carbonates have notably retreated. Under the serpentines, as compared with the theoretical mineral, No. 4, the succeeding analyses are all notably rich in iron. Except in the cases of Nos. 10 and 11, they are remarkably uniform considering their diverse origin. In No. 10 the SiO_2 drops, probably from the presence of magnetite while in the last the pyroxene of the original peridotite has contributed considerable lime. In all these rocks Al_2O_3 is notably low. It is most abundant in No. 8, a serpentine that is derived from a rock with much augite. Chromium is a rather characteristic element in serpentines that result from basic igneous rocks, and nickel can be very generally detected on analysis. Lime practically fails except in No. 11. It should be appreciated that as a mineral, serpentine is a unisilicate, whereas talc is a bisilicate, and this explains the much larger percentage of silica in the latter. The soapstones are fairly pure, aggregates of talc, as a comparison of Nos. 12 and 13 with No. 14 will indicate.

Mineralogical Composition. Varieties. The ophicalcites are mottled rocks consisting of irregular or rounded masses of green serpentine embedded in white calcite and dolomite. The proportions of the constituent minerals are variable. The serpentine may be in small nodules a fraction of an inch in diameter or in large stringers and masses several feet across. This irregularity renders it difficult in quarrying to preserve a uniform grade. The stone is mottled green and white, and when uniform is a very beautiful one. The serpentine varies from dark green or almost black, to light clear shades, and has been derived in a number of cases, as has been shown by G. P. Merrill,* from original pyroxene crystals.

The ophicalcites are therefore in many cases alteration products from a crystalline limestone, that has been surcharged with pyroxenes, and this itself may probably be referred in most cases to an original siliceous, magnesian sediment, recrystallized by regional metamorphism.

Ophicalcites are also called ophiolites, serpentinous marbles and verd antique. The syllable "ophi," in all these words is derived from the Greek for serpent and ophicalcite means therefore a serpentinous limestone.

The serpentines are green or red aggregates of scales, fibres or massive individuals of the mineral serpentine. They display considerable variety of texture according to the characters of these components. Other minerals are not especially prominent. Grains of chromite or magnetite may be detected and garnets of the variety pyrope are sometimes well developed. Veinlets of calcite or of magnesian carbonates ramify through the rock in many exposures. Remains of the original olivine, pyroxene, or hornblende from which the serpentine has been derived may often be detected and biotite or some hydrated magnesian mica is not infrequent. The varieties of the mineral serpentine are numerous, but many of them are too rare to be serious rock-makers. Almost all serpentines have been formed by the alteration of basic igneous rocks, among which the pyroxenites and peridotites are the chief contributors. Hornblende schists also yield them and G. F. Becker has recorded the remarkable case of sandstones that pass into them in the Coast Ranges of California.

Soapstones, called also steatites, are chiefly talc as the analyses show. Quartz veinlets often run through the rock and scattered grains of quartz are not infrequent. Magnesian carbonates

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*G. P. Merrill, *Amer. Jour. Sci.*, March, 1889; *Proc. U. S. Nat'l. Museum*, XII, 595, 1890.

are likewise evident in many exposures. In the case of the Gouverneur beds of talc (see Anal. 13), C. H. Smyth has shown that the original minerals have been tremolite and enstatite, and that the beds occur in crystalline limestone, but from what the tremolite and enstatite have been derived is a hard problem. Two reasonable sources suggest themselves, either a siliceous dolomite, or a non-ferruginous, basic intrusive. The soapstones are not particularly abundant rocks but are of economic value where met. They are close relatives of the talc schists earlier cited.

Alteration. The serpentinous rocks themselves are thoroughly altered derivatives from fresher anhydrous ones and in their further decomposition simply soften to incoherent dirt and clay. The more resistant, included minerals are thus set free, and as in the case of platinum and garnets they may be concentrated in gravel.

Distribution. Ophicalcites are most abundant in Quebec, the northern Green Mountains and the foothills of the Adirondacks. The serpentines are especially notable on Staten Island, in southeastern Pennsylvania and the neighboring parts of Maryland, where the gabbros, as stated on p. 52, and their related rocks are abundant. They share in an important belt of these basic intrusives in North Carolina and Georgia. In the basic igneous rocks around Lake Superior, they are occasionally met as alteration products. In the Coast ranges the serpentines are of very great importance, and in part are altered sediments. They are likewise common abroad, and in a minor capacity appear in many metamorphic districts. Soapstone is much less common, but is met in this country as a minor member in much the same regions as the serpentines and crystalline dolomites.

CHAPTER XII.

THE METAMORPHIC ROCKS, CONCLUDED. THE ROCKS PRODUCED BY ATMOSPHERIC WEATHERING. THE DETERMINATION OF THE METAMORPHIC ROCKS.

Introduction. It is a matter of common observation that outcrops of rock and loose boulders are always more or less decomposed and broken down or "weathered" for a greater or less distance below their surfaces. This may not be serious enough to prevent the accurate recognition of the rock, and usually within the area once covered by the great ice sheet of the Glacial Period it is not, because the moving ice has ploughed away all loose and decomposed materials, but south of the terminal moraine, and above all in the tropics, the decomposition is excessive and may produce to a depth of a hundred feet or more a mass of alteration products that give of themselves slight, if any, clue to their originals. This is a common experience in the Southern States, where, as well as in Central and South America, the indefinite character of the surface rock throws great difficulties in the way of accurate geological mapping. So difficult at times is the determination of the country rock that, for example, during field work in Brazil, O. A. Derby has felt compelled to resort to the panning out of the surface materials with a gold-seeker's pan in order, by concentrating the heavy but small and undecomposed accessory minerals, such as zircon, titanite, monazite, xenotime, apatite and others, to get some clue from their characteristic associations to the original rock. Many travelers have noted the brilliant colors of the soils of latitudes toward the equator and the comparatively somber tones of those toward the poles.

These products of weathering are so widespread, therefore, and so individual that a few pages have been reserved for their particular mention. Special names for them have been suggested at various times. The oldest one and the one most current is laterite. The word means brick earth and was originally applied to the red or brown ironstained surface soils occurring in the tropical lands, and derived by direct decomposition from the country rock in place. It has been applied in later years, however, to all sorts of these surface soils from whatever rocks derived, and whether colored red or not. G. F. Becker, of the U. S. Geological Survey, has recently (1895) proposed saprolite,* a word meaning literally rotten rock, as "a general name for thoroughly decomposed, earthy, but untransported rock." This is practically the modern use of laterite, although it is broader than the latter's original application. The U. S Geological Survey in the invaluable series of atlas sheets now being issued employs the term "surficial," *i. e.*, surface rocks, as a general designation for these untransported products of decomposition. We also often speak of residual clay as was done on pp. 66 and 67 for the less soluble aluminous residues left behind in the removal of the more soluble portions of limestones.

The general scope and application of these names having been set forth, a brief consideration will be given to the mineralogical processes of change that have produced them from several of the commoner groups of rock.

The chief causes of this superficial breaking down or "degeneration," as it has been aptly called by G. P. Merrill,† are the chemical action of rain and ground-waters, especially when charged with carbonic acid or other dissolved matter; organic life, both vegetable and animal, operating through the agency of the organic acids produced by their living processes or by their decomposing remains; and the mechanical disintegration produced by changes of temperature, by the freezing of water and by swelling from hydration or from some of the chemical or mineralogical changes among those referred to above. Although having no connection with these atmospheric processes, yet hot springs and allied exhalations from dying volcanic activity bring about closely similar results and are able to change great sheets of volcanic rock to brilliantly variegated masses of clay and kaolin. At the Falls of the Yellowstone River, in the National Park, these are wonderfully and impressively displayed, more than a thousand feet of rhyolite having been changed practically to kaolin.

Under the action of the chemical agents the more easily soluble

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*Goldfields of the Southern Appalachians, p. 43, XVI. *Ann. Rep. Dir. U. S. Geol. Survey.*

† Bulletin of the Geological Society of America, VII., 378.

elements are removed or are put in such relations to one another as to facilitate their rearrangement in new and secondary combinations. In the rocks composed of silicates the most vulnerable oxides are lime, magnesia, potash and soda. Iron oxides also suffer extensively, but the ferric form is sometimes very resistant. Silica yields more or less, especially to the alkaline solutions from the potash and soda referred to above. Alumina, on the whole, is least readily attacked of all, and is usually the one that furnishes the best basis of comparison between analyses of altered and unaltered materials.

Among the igneous and metamorphic rocks open or porous varieties naturally suffer more than compact and finely crystalline ones. Rocks high in the bases that are most readily attacked chemically, are easier victims than those especially rich in the resistant ones. Basic rocks, therefore, with their high percentages of lime and magnesia and their relatively low silica, suffer especially, whereas granites and related gneisses are much more stubborn subjects, the large amount of quartz in them furnishing a very resistant component.

Granites, syenites, acid diorites and their corresponding porphyritic types alter especially through the feldspathic member present. The constitueut quartz is but slightly affected, and the dark silicates are not present in sufficiently large amounts to be very serious factors. The resulting product is a kaolinized or clayey mass through which are distributed quartz grains, and which is more or less stained by the hydrated oxide of iron that is yielded to some extent by the dark silicates. The characteristic products of the latter are also present in small amounts, but are more extensively mentioned subsequently. The exposed ledges furnish loose pieces that often weather in concentric shells and simulate rounded water-worn boulders. The net result is a large contribution of clay and sand to sedimentary or eolian deposits it may be at a great distance.

In the basic igneous or metamorphic rocks the dark ferro-magnesian and aluminous silicates are in excess, and in decomposition their peculiar products predominate. The distinctively magnesian ones yield serpentine, the aluminous change to chlorite. Both these minerals are prevailingly green, and dark green surficial rocks result. The abundance of iron in them leads to the formation of very rusty outcrops.

In the case of limestone, the lime and magnesia are dissolved away, while the alumina, silica and iron oxides remain behind in the mantle of impure residual clay already referred to; the other sedimentary rocks suffer especially from mechanical processes, although chemical changes are not lacking among them, for, as remarked on page 107 regarding analysis No. 1, of page 63, during the breaking up considerable leaching may result that leads to the production of nearly chemically pure quartz sand.

The mechanical and associated chemical breaking down of rocks tends to place them in more favorable conditions for further chemical alterations, and for erosion and removal.

All the changes in the weathering of rocks have been well described by M. E. Wadsworth as "resulting from the general dissipation and degradation of the potential energy of the constituents of the earth's crust in the universal passage of matter from an active state towards a passive and inert condition."*

THE DETERMINATION OF THE METAMORPHIC ROCKS.

The rocks resulting from contact metamorphism are rather of local interest, than of wide, areal distribution. The spotted schists and slates, and the hornstones are readily recognized by a practiced observer. The crystalline limestones even when charged with silicates may closely resemble the products of regional metamorphism. In dealing with the latter, familiarity with well characterized types is the safest guide. The gneisses are at once apparent from their laminated character and granitoid texture. Transition members between them and the mica-schists on the one hand, and the hornblende-schists on the other, may cause hesitation as to which group they belong to. The finely laminated ones are certainly members of the schists, those with prevailing mica belonging with the mica-schists, those with prevailing hornblende, with the hornblende-schists. Again as the fineness of the lamination or foliation increases, the schists pass into the phyllites and slates, that are easily recognized. The quartzites likewise present little difficulty as they are practically hard sandstones. The crystalline limestones and dolomites are only to be distinguished by the ease or difficulty of obtaining effervescence. The ophicalcites look like no other rocks, and the serpentines and soapstones are

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*The Theories of Ore Deposits, *Proc. Bost. Soc. Nat. Hist.* Vol. XXIII., p. 202. 1884.

also at once apparent. The soapy feel of all these magnesian rocks aids in their recognition. There are, of course, rare and obscure metamorphic rocks that cause trouble, but such, just as in the case of the finely crystalline igneous rocks, are best referred to someone familiar with the use of the microscope.

GLOSSARY.

NOTE.—In the following definitions, when fuller explanations are to be found in preceding pages, references are given to them and they should be consulted. No attempt has been made to unnecessarily repeat previous statements.

A

Absarokite, a general name given by Iddings to a group of igneous rocks in the Absaroka range, in the eastern portion of the Yellowstone Park. They have porphyritic texture with phenocrysts of olivine and augite in a groundmass, either glassy or containing leucite, orthoclase or plagioclase, one or several. They range chemically, SiO_2, 46–52; Al_2O_3, 9–12; MgO, 8–13; alkalies, 5–6.3 with potash in excess. The name is of greatest significance when taken in connection with shoshonite and banakite. Jour. of Geol. III., 936.

Ablation, a name applied to the process whereby residual deposits are formed by the washing away of loose or soluble materials.

Abyssal-rocks, synonym of plutonic rocks as used in preceding pages. The word has been suggested and especially used by W. C. Brögger.

Accessory components or minerals in rocks are those of minor importance or of rare occurrence, whose presence is not called for by the definition of the species.

Acidic, a descriptive term applied to those igneous rocks that contain more than 65% SiO_2, as contrasted with the medium of 65%–55% and the basic at less than 55%; still the limits are somewhat elastic.

Acmite-trachyte, a trachyte whose pyroxene is acmite or ægirine and whose feldspar is anorthoclase. It therefore differs from normal trachyte in its prevailing soda instead of potash, as is shown by the acmite, a soda-pyroxene, and the anorthoclase, a soda-feldspar. The acmite-trachytes are intermediate between the true trachytes and the phonolites. They were first described from the Azores (Mügge, Neues Jahrbuch. 1883, II., 189) and have also been found in the Crazy Mountains, Mont.; see p. 26, Anals. 4 and 5.

Adamellite, a name proposed by Cathrein as a substitute for tonalite, on the ground that tonalite is a hornblende-biotite granite, rich in plagioclase, rather than a diorite. The name is derived from Monte Adamello, near Meran, Tyrol, the locality of tonalite. Neues Jahrb. 1890, I., 75. Brögger uses it for acidic quartz-monzonite. Eruptions-folge bei Predazzo, 61.

Adinole, a name for dense felsitic rocks composed chiefly of an aggregate of excessively fine quartz and albite crystals, such that on analysis the percentage of soda may reach 10. Actinolite and other minerals are subordinate. Adinoles occur as contact rocks, associated with diabase intrusions and produced by them from schists (compare spilosite and desmite); and as individual beds in metamorphic series. (Compare porphyroid, hälleflinta.) The name was first given by Beudant, but has been especially revived by Lossen. Zeits. d. d. Geol. Ges., XIX., 572, 1867.

Aerolite, a synonym of meteorite.

Agglomerate, a special name for volcanic breccias as distinguished from other breccias and from conglomerates.

Akerite, a special name coined by Brögger for a variety of syenite at Aker, Norway, that is a granitoid rock consisting of orthoclase, considerable plagioclase, biotite, augite and some quartz. (W. C. Brögger, Zeitsch. f. Krys., 1890, 43.)

Algovite, a name proposed by Winkler, for a group of rocks, practically diabases, or porphyritic phases of the same, in the Algäuer Alps. They also embrace gabbros according to Roth, and are doubtless various textural varieties of an augite-plagioclase magma. Neues Jahrbuch, 1895, 641.

Allotriomorphic, an adjective coined by Rosenbusch in 1887 to describe those minerals in an igneous rock which do not possess their own crystal faces or boundaries but which have their outlines impressed on them by their neighbors. They result when a number of minerals crystallize at once so as to interfere with one another. They are especially characteristic of granitoid textures. The word was unnecessary, as xenomorphic had been earlier suggested for the same thing, but it is in more general use than xenomorphic. See also anhedron.

Alluvium, Lyells' name for the deposit of loose gravel, sand and mud that usually intervenes in every district between the superficial covering of vegetable mould and the subjacent rock. The name is derived from the Latin word for an inundation (Elements of Geol., 6th Ed., N. Y., 1859, p. 79). Used by Naumann as a general term for sediments in water as contrasted with eolian rocks. It is generally used to-day for "the earthy deposit made by running streams or lakes, especially during times of flood." (Dana's Manual, 1895, p. 81.) In a stratigraphical sense it was formerly employed for the more recent water-sorted sediments as contrasted with "diluvium," or the stratified and unstratified deposits from the melting of the continental glacier of the Glacial Period. This use, with fuller study of the Glacial times, is practically obsolete.

Alnoite, a very rare rock with the composition of a melilite basalt, that was first discovered in dikes on the island of Alnö, off the coast of

Norway. The special name was given it by Rosenbusch to emphasize its occurrence in dikes and its association as a very basic rock, with nepheline syenite. Alnoite has been discovered near Montreal by F. D. Adams. (Amer. Jour. Sci. April, 1892, p. 269.) and at Manheim Bridge, N. Y., by C. H. Smyth, Jr. (Amer. Jour. Sci. Aug., 1893, 104).

Alsbachite, a name given by Chelius to a variety of granite-porphyry, forming dykes in Mt. Melibocus, and containing large mica crystals and rose-red garnets. Notizbl. Ver. Erdk, zu Darmstadt, 1892. Heft. 13, 1.

Alum-shales, shales charged with alum which in favorable localities may be commercially leached out and crystallized. The alum results from the decomposition of pyrites. The sulphuric acid thus produced reacts on the alumina present, yielding the double sulphate that is alum.

Amphibole, the generic name for the group of bisilicate minerals whose chief rock-making member is hornblende. It is often prefixed to those rocks which have hornblende as a prominent constituent, as amphibole-andesite, amphibole-gabbro, amphibole-granite, etc.

Amphibolite, a metamorphic rock consisting chiefly of hornblende, or of some member of the amphibole group. It is as a rule a synonym of hornblende-schist, but is preferable to the latter when the schistosity is not marked. See p. 101.

Amygdaloids are cellular lavas, whose cavities, caused by expanding steam-bubbles, resemble an almond in size and shape. Basaltic rocks are most prone to develop them. The term is used in the form of the adjective, amygdaloidal, and properly should be limited to this. As a noun it is also employed for secondary fillings of the cavities, which are usually calcite, quartz or some member of the zeolite group. Amygdaloidal rocks are of chief interest in America, because certain basaltic lava sheets on Keweenaw Point, Lake Superior, have their amygdules filled with native copper and are important sources of the metal. Amygdaloidal cavities are limited to the upper and lower portions of lava sheets. The name is derived from the Greek word for almond.

Analcite-basalt, a variety of basalt whose feldspar is more or less replaced by analcite. The analcite is at times in such relations as to give reason for thinking it an original mineral and not an alteration product from feldspar. Analcite basalts occur in the Highwood Mountains, Mont., (see W. Lindgren, 10th Census, XV., 727, Proc. Calif. Acad. Sci., Ser. II., Vol. III., p. 51. Comptes Rendus, Fifth Internat. Geol. Cong., 364). Analcite-diabase has been met in California. (H. W. Fairbanks, Bull. Dept. Geol. Univ. of Calif., I., 173. See also in this connection teschenite.)

Anamesite, an old name suggested by von Leonhard in 1832, for those finely crystalline basalts, which texturally stand between the dense typical basalt, and the coarser dolerites. The name is from the Greek for "in the middle."

Andalusite-hornstone, a compact contact rock containing andalusite. It is usually produced from shales or slates by intrusions of granite.

Andesite, volcanic rocks of porphyritic or felsitic texture, whose crystallized minerals are plagioclose and one or more of the following: biotite, hornblende and augite. The name was suggested by L. von Buch in 1836, for certain rocks from the Andes, resembling trachytes, but whose feldspar was at first thought to be albite, and later oligoclase. See p. 40.

Anhedron, a name proposed by L. V. Pirsson for the individual mineral components of an igneous rock, that lack crystal boundaries, and that cannot therefore be properly called crystals according to the older and most generally accepted conception of a crystal. Xenomorphic and allotriomorphic are adjectives implying the same conception. The name means without planes. Bulletin Geol. Society of America, Vol. VII., p. 492, 1895.

Anogene, a general name for rocks that have come up from below; *i. e.*, eruptive rocks. See p. 13.

Anorthite-rock, a name given by R. D. Irving to a coarsely crystalline, granitoid rock, from the Minnesota shore of Lake Superior, that consists almost entirely of anorthite (Monograph V., U. S. Geol. Survey, p. 59). The rock is a feldspathic extreme of the gabbro group, practically an anorthosite formed of anorthite. Geol. Can.-1863-22

Anorthosite, a name applied by T. Sterry Hunt (Amer. Jour. Sci., Nov., 1869) to granitoid rocks that consist of little else than labradorite and that are of great extent in eastern Canada and the Adirondacks. The name is derived from *anorthose*, the French word for plagioclase, and is not to be confused with anorthite, with which it has no necessary connection, although anorthosite is used as a general name for rocks composed of plagioclase. Mt. Marcy and the neighboring high peaks of the Adirondacks are formed of it. The rocks are extremes of the gabbro group, into whose typical members they shade by insensible gradations. See p. 50.

Apachite, a name suggested by Osann, from the Apache, or Davis Mountains of Western Texas, for a variety of phonolite, that varies from typical phonolites in two particulars. It has almost as much of amphiboles and of ænigmatite as of pyroxene, whereas in normal phonolites the former are rare. The feldspars of the groundmass are generally microperthitic. Tscher. Mitth., XV., 454.

Aphanite, an old name, now practically obsolete, for dense, dark rocks, whose components are too small to be distinguished with the eye. It was chiefly applied to finely crystalline diabases. An adjective aphanitic is still more or less current.

Aplite is now chiefly applied to the muscovite-granite that occurs in dikes, and that is, as a rule, finely crystalline. Its original application was to granites poor or lacking in mica. See p. 31. The name is from the Greek for simple.

Apo, the Greek preposition for "from," suggested by F. Bascom as a prefix to the names of various volcanic rocks to describe the devitrified or silicified varieties, mostly of ancient date, that result from them, and that indicate their originals only by the preservation of characteristic textures. Thus apobsidian, aporhyolite, apandesite, apobasalt, etc., have been used. (See p. 22.) Many rocks called by the old indefinite name petrosilex are of this character. Journal of Geology, I., 828, Dec., 1893.

Arenaceous, an adjective applied to rocks that have been derived from sand, or that contain sand.

Argillite, a synonym of slate.

Arkose, a special name for a sandstone rich in feldspar fragments, as distinguished from the more common richly quartzose varieties. See p. 64.

Aschaffite, a name suggested by Gümbel for a dike rock occurring near Aschaffenburg, Bavaria. (Bavaria, Vol. IV., Heft. 11, p. 23.) It is defined by Rosenbusch as a dioritic dike rock, containing quartz, plagioclase and biotite as the chief dark silicate.

Ashbed diabase, a local name used on Keweenaw Point, Lake Superior, for a rock resembling a conglomerate, but which is interpreted by Wadsworth as a very scoriaceous amygdaloidal sheet into which much sand was washed in its early history. See Monograph V., U. S. Geol. Surv., p. 138.

Asiderite. Daubrée's name for stony meteorites that lack metallic iron.

Asperite, a collective name suggested by G. F. Becker for the rough cellular lavas whose chief feldspar is plagioclase, but of which it is impossible to speak more closely without microscopic determination. The name is intended for general field use much as trachyte was employed in former years, and it is coined from the Latin word for rough. See p. 41. Also Monograph XIII., U. S. Geol. Surv., p. 151.

Ataxite. See under Taxite.

Augen, the German word for eyes; used as a prefix before various rock names, but more especially gneiss, to describe larger minerals or aggregates of minerals, which are in contrast with the rest of the rock. In the gneisses, feldspars commonly form the augen and are lenticular with the laminations forking around them, in a way strongly suggesting an eye. The term is seldom used in any other connection than with gneiss in America.

Augite, the commonest rock-making pyroxene. The name is used as a descriptive prefix to many rocks that contain the mineral, as for instance augite-andesite, augite-diorite,augite-gneiss, augite-granite, augite-syenite, etc.

Augitite, non-feldspathic, porphyritic rocks, consisting essentially of a glassy groundmass, with disseminated augite and magnetite. Various minor accessories also occur. The name was first applied by Doelter to lavas from the Cape Verde Islands. (Verhandl, d. k. k. Geol. Reichsanst. 1882, 143.) See above, pp. 44, 45.

Aureole, the area surrounding an igneous intrusion that is affected by contact metamorphism. See p. 87.

Authigenous, an adjective coined by Kalkowsky to describe those minerals which form in sediments after their deposition, as for instance during metamorphism. The name emphasizes in its etymology the local origin of the minerals as contrasted with that of the other components, they having been brought from a distance.

Autochthonous, an adjective derived from two Greek words, meaning indigenous. It is applied to those rocks that have originated in situ, such as rock salt, stalagmitic limestones, peat, etc., but it is of rare use.

Automorphic is the contrasted term with xenomorphic or allotriomorphic, and is used to describe those minerals in rocks which have their own crystal boundaries. The later suggested word, idiomorphic, means the same thing and is somewhat more widely used.

Axiolite, a term coined by Zirkel in his report on Microscopical Petrography, for the U. S. Geol. Survey along the Fortieth Parallel, 1876, to describe those spherulitic aggregates that are grouped around an axis rather than around a point. The application comes in microscopic work rather than in ordinary determination.

B

Banakite, a general name given by Iddings to a group of igneous rocks in the eastern portion of the Yellowstone Park and chiefly in dykes. They are porphyritic and richly feldspathic. The phenocrysts are labradorite and the groundmass consists of alkali-feldspars. A little biotite and subordinate augite may be present. Chemically they range SiO_2, 51–61; Al_2O_3, 16.7–19.6; CaO, 3.5–6; MgO, 1–4; Na_2O, 3.8–4.5; K_2O, 4.4–5.7. The group should be considered in connection with absarokite and shoshonite. Journ. of Geol. III., 937.

Banatite, a name coined by B. v. Cotta in 1865 to describe the dioritic rocks that are connected with a series of ore deposits in the Austrian province of the Banat. Accurate microscopical study has shown them to be of such varying mineralogy that the name has now slight definite significance. The rocks are largely quartz-diorites. Erzlagerstätten im Banat und in Serbien, 1865.

Barolite, Wadsworth's name for rocks composed of barite or celestite. Rept. of State Geol. Mich., 1891–92, p. 93.

Barysphere, a term for the deep interior portions of the earth, presumably composed of heavy metals or minerals. It is contrasted with lithosphere, the outer stony shell.

Basalt, a word of ancient but uncertain etymology as stated on p. 43. It is employed as a rock name in its restricted sense for porphyritic and felsitic rocks consisting of augite, olivine and plagioclase with varying amounts of a glassy base which may entirely disappear. In a broader sense the basalt or basaltic group is used to include all the dark, basic volcanic rocks, such as the true basalts; the nepheline-, leucite- and melilite-basalts; the augitites and limburgites; the diabases, and melaphyres. The word basalt is an extremely useful field name, as in many instances the finer discriminations can only be made with the microscope.

Basanite, a very old term, first used as a synonym of basalt; also formerly applied to the black, finely crystalline quartzite, used by old-time workers in the precious metals as a touch-stone or test-stone to distinguish gold from brass by the streak. This variety was often called Lydian stone or lydite. Basanite is now universally employed for those volcanic rocks, that possess a porphyritic or felsitic texture and that contain plagioclase, augite, olivine and nepheline, or leucite, one or both, each variety being distinguished by the prefix of one, or the other, or of both of the last named minerals. See p. 44.

Basanitoid, a term suggested by Bücking for basaltic rocks, without definite nepheline, but with a gelatinizing glassy base (H. Bücking, Jahrb. d. k. k. preus. Landesanst., 1882).

Base or **Basis,** is employed to describe that part of a fused rock magma that in cooling fails to crystallize as recognizable minerals, but chills as a glass or related amorphous aggregate. It differs thus from groundmass, which is the relatively fine portion of a porphyritic rock as distinguished from the phenocrysts.

Basic, a general descriptive term for those igneous rocks that are comparatively low in silica, 55 or 50 per cent. is the superior limit. See also *Acidic* and *Medium*.

Bathylite, a name suggested by Suess for the vast irregular masses of plutonic rocks that have crystallized in depth and that have only been exposed by erosion. See p. 12.

Beerbachite, a name given by Chelius to certain small dikes, associated with and penetrating large gabbro masses, and having themselves the composition and texture of gabbro. The name was given in the attempt to carry out the questionable separation of the dike rocks from large plutonic or volcanic masses of the same mineralogy and structures. Notizbl. Ver. Erdkunde Darmstadt, 1892, Heft. 13, p. 1.

Belonite, rod or club-shaped microscopic minerals, which usually occur as embryonic crystals in a glassy rock.

Benches, a name applied to ledges of all kinds of rock that are shaped like steps or terraces. They may be developed either naturally in the ordinary processes of land-degradation, faulting, and the like; or by artificial excavation in mines and quarries.

Beresite, a name coined by Rose many years ago for a muscovite-granite that forms dikes in the gold district of Beresovsk in the Urals. It is, therefore, practically a synonym of aplite, as earlier defined, but some of the beresites have since been shown to be practically without feldspar, and to form a very exceptional aggregate of quartz and muscovite. (Arzruni, Zeitsch. d. d. g., Gesellsch., 1885, 865).

Binary-granite, a term more or less used in older geological writings for those varieties of granite that are chiefly quartz and feldspar. See p. 31.

Biotite is used as a prefix to many names of rocks that contain this mica; such as biotite-andesite, biotite-gneiss, biotite-granite, etc.

Bituminous, an adjective applied to rocks with much organic, or at least carbonaceous matter, mostly in the form of the tarry hydrocarbons which are usually described as bitumen.

Blue-ground, local miners' name for the decomposed peridotite or kimberlite that carries the diamonds in the South African mines.

Bombs, masses of lava expelled from a volcano by explosions of steam. They fall as rounded masses and lie on the slopes of the cone, or become buried in tuffs.

Boninite. Petersen's name for a glassy phase of andesite with bronzite, augite and a little olivine, from the Bonin Islands, Japan. Jahrb. Hamburg Wissensch. Anst., VIII., 1891. Compare sanukite.

Borolanite, a rare rock related to the nepheline-syenites and described by Horne and Teall from Borolan, Sutherlandshire, Scotland. It has granitoid texture, and consists principally of orthoclase and the variety of garnet, called melanite. As accessory minerals, biotite, pyroxene, alteration products of nepheline, sodalite, titanite, apatite and magnetite are met. (Trans. Roy. Soc. of Edinburgh, 1892, p. 163.)

Bostonite, a name proposed by Hunter and Rosenbusch for certain dikes, having practically the mineralogical and chemical composition of trachytes or porphyries, except that anorthoclase (and therefore soda) is abnormally abundant and dark silicates are few or lacking. They are much the same as dike-keratophyres and were especially named in carrying out the questionable separation of the dike-rocks as a distinct ground division from the plutonic and volcanic. The name was suggested by their supposed presence near Boston, Mass., but Marblehead, 20 miles or more distant is their nearest locality. They have been since met in largest amount around Lake Champlain and in the neighboring parts of Canada. Tscher. Min. u. Petrog. Mitth., 1890, 447. See also Bull. 107, U. S. Geol. Survey.

Bouteillenstein, *i. e.*, bottlestone, a peculiar green and very pure glass, found as rolled pebbles near Moldau, Bohemia. It is also called moldauite and pseudochrysolite, the latter from its resemblance to olivine. It is not certainly a rock, as it may be a prehistoric slag or glass.

Boulder-clay, unsorted glacial deposits, consisting of boulders, clay and mud; till, hardpan.

Breccia, a fragmental rock whose components are angular and therefore as distinguished from conglomerates are not water-worn. There are friction or fault breccias, talus-breccias and eruptive breccias. The word is of Italian origin. See p. 59.

Broccatello, an Italian word for a brecciated and variegated marble.

Bronzite is often used as a prefix to the names of rocks containing the mineral. Rocks of the gabbro family are the commonest ones that have the prefix.

Buchnerite, a name proposed by Wadsworth for those peridotites, terrestrial and meteoric, which consist of olivine, enstatite (bronzite) and augite. The name was given in honor of Dr. Otto Buchner, an authority on meteorites. Lithological Studies, 1884, p. 85.

Buchonite, a special name given by Sandberger to a nepheline-tephrite that contains hornblende. Sitzungsberichte d. Berl. Akad. Wis., July, 1872, 203; 1873, vi.

Buhrstone, a silicified fossiliferous limestone, with abundant cavities which were formerly occupied by fossil shells. Its cellular character and toughness occasioned its extensive use as a millstone in former years.

C

Calc-schist, schistose rocks, rich in calcite or dolomite and forming intermediate or transitional rocks between the mica-schists and crystalline limestones. See p. 101.

Camptonite, a name given by Rosenbusch to certain dike rocks, having in typical cases the mineralogical composition of diorites, *i. e.*, with dark brown hornblende, plagioclase, magnetite, and more or less augite. They are often porphyritic in texture, and may even have a glassy groundmass. Without the microscope camptonites usually appear as dark basaltic rocks with a few shining crystals of hornblende or augite; their determination is essentially microscopic. Intimately associated with the camptonites of typical composition have been found others corresponding to all varieties of basaltic rocks. Such with prevailing augite have been called augite-camptonite. The name camptonite is derived from the township of Campton, in the Pemigewasset Valley, N. H. The original camptonites were discovered near Livermore Falls, on the Pemigewasset river, many years ago, by O. P. Hubbard. They were microscopically described by G. W. Hawes in 1878, and on this determination Rosenbusch based the name. They, or their near relatives, have often intimate associations with nepheline syenites. (See also, monchiquite, fourchite, ouachitite.) Camptonites are especially abundant throughout the Green Mountains and near Montreal. G. W. Hawes, Amer. Jour. Sci., 1879, XVII., 147. H. Rosenbusch, Massigen Gesteine, 1887, 333. Bulletin 107, U. S. Geol. Surv.

Carbonolite, Wadsworth's name for carbonaceous rocks. Rept. State Geol. Mich., 1891–92, p. 93.

Cataclastic, a structural term applied to those rocks that have suffered mechanical crushing in dynamic metamorphism.

Catawberite, a name given by O. Lieber to a rock in South Carolina that is an intimate mixture of talc and magnetite. Gangstudien, III., 353, 359.

Catlinite, a local name in Minnesota for a red argillaceous sandstone, presumably of Cambrian age, that was used by the Indians for pipe bowls. C. T. Jackson, Amer. Jour. Sci., 1839, 388.

Catogene, *i. e.*, sedimentary rocks whose particles have sunk from above downward.

Cement, the material that binds together the particles of a fragmental rock. It is usually calcareous, siliceous or ferruginous. See p. 64. The word is also used in gold-mining regions to describe various consolidated fragmental aggregates, breccia, conglomerate and the like that are auriferous.

Chalk, a marine calcareous and excessively fine organic sediment usually consolidated.

Chert, compact siliceous rock formed of chalcedonic or opaline silica, one or both, and of organic or precipitated origin. See pp. 74, 80, 81. Cherts often occur distributed through limestone affording cherty limestones. Flint is a variety of chert. Cherts are especially common in the subcarboniferous rocks of southwest Missouri.

Chlorite, a general name for the green secondary hydrated silicates containing alumina and iron, and derived especially from augite, hornblende and biotite. Chlorite is used as a prefix to various names of rocks that contain the mineral, such as chlorite schist. The name is derived from the Greek word for green.

Chlorophyr, a name given by A. Dumont to certain porphyritic quartz diorites near Quenast, Belgium. See Delesse, Bull. Soc. Geol. de France, 1850, 315.

Clastic, descriptive term applied to rocks formed from the fragments of other rocks; fragmental.

Clay, general name for the fine aluminous sediments that are plastic. Though usually soft, they may be so hard as to need grinding before the plasticity manifests itself, as in numerous fire clays. See p. 67.

Clay slate, metamorphosed clay, with new cleavages developed by pressure and shearing. The term is used in distinction to mica-slate, and other slaty rocks. See p. 108.

Claystone-porphyry, an old and somewhat indefinite name for those porphyries whose naturally fine groundmass is more or less kaolinized, so as to be soft and earthy, suggesting hardened clay.

Clinkstone. See phonolite.

Composite dike, a dike formed by two intrusions of different ages into the same fissure (W. Judd, Quar. Jour. Geol. Soc., 1893, 536).

Concretions, spheroidal or discoid aggregates formed by the segregation and precipitation of some soluble mineral like quartz or calcite around a nucleus, which is often a fossil.

Cone-in-cone, a curious structure, occasionally met in clay rocks, whereby two opposing and interlocking sets of cones or pyramids are developed, with their axes parallel and their bases in approximately parallel surfaces.

Conglomerate, consolidated gravel. See p. 62.

Consanguinity, a term used by Iddings to describe the genetic relationship of those igneous rocks which are presumably derived from a common, parent magma. See p. 57, and Bull. Phil. Soc. Washington XI., 89.

Contact, the place or surface where two different kinds of rocks come together. Although used for sedimentary rocks, as the contact between a limestone and sandstone, it is yet more especially employed as between igneous intrusions and their walls. The word is of wide use in western mining regions on account of the frequent occurrence of ore-bodies along contacts. On contact-metamorphism, see pp. 85–92.

Cordierite, a synonym of iolite or dichroite, employed as a prefix to those rocks that contain the mineral, as cordierite-gneiss.

Cornubianite, a name coined by Boase from the classic name for Cornwall, England, to describe a contact hornfels, consisting of andalusite, mica and quartz. It was proposed as a substitute for an earlier but indefinite term proteolite. Bonney suggests restricting cornubianite to tourmaline hornfels. Quar. Jour. Geol. Soc., 1886, 104

Corrasion, geological term for the wearing away of rocks by grit suspended in moving water or air; to be distinguished from erosion.

Corroded crystals, phenocrysts that after crystallization are more or less reabsorbed or fused again into the magma.

Corsite, a name applied by Zirkel to the orbicular or spheroidal diorite from Corsica; synonym of napoleonite. Lehrb. d. Petrographie, 1866, II., 133, 320.

Cortlandite, a special name given by G. H. Williams to a peridotite that consists chiefly of hornblende and olivine and that occurs in the so-called Cortland series of igneous rocks in the township of Cortland, just south of Peekskill, on the Hudson River. This rock had been previously called hudsonite by E. Cohen, a name rejected by Williams because already used for a variety of pyroxene. Amer. Jour. Sci., Jan., 1886, 30.

Corundolite, Wadsworth's name for rocks composed of corundum or emery. Rept. State Geol. Mich., 1891–92, p. 92.

Crenitic, a word derived from the Greek for spring, and especially used by T. S. Hunt for those rocks which were thought by him to have come to the surface in solution and to have been precipitated. He used the so-called "crenitic hypothesis" to explain certain schists whose feldspars were supposed to have been originally zeolites, but his views have received slight, if any, support. Proc. Roy. Soc. Canada, Vol. II., Sec. III., 1884. Reprint, p. 25. Crenitic is also used by W. O. Crosby to describe those mineral veins which have been deposited by uprising springs. Technology Quarterly, April, 1894, p. 39.

Cross-bedding, or **Cross-stratification**, descriptive terms applied to those minor or subordinate layers in sediments that are limited to single beds, but that are inclined to the general stratification. They are caused by swift local currents, deltas, or swirling wind-gusts, and are especially characteristic of sandstones, both aqueous and eolian. See pp. 64, 65.

Crustification, the English equivalent of a term suggested by Posepny for those deposits of minerals and ores that are in layers or crusts and that, therefore, have been distinctively deposited from solution. Trans. Amer. Inst. Min. Eng., XXIII., 207, 1893.

Crypto-crystalline, formed of crystals of unresolvable fineness, but not glassy. A submicroscopical crystalline aggregate.

Crystallites. The term is most properly applied only to small, rudimentary or embryonic crystals, not referable to a definite species, but it is also used as a general term for microscopic crystals.

Cumberlandite, a name derived from Cumberland Hill, R. I., proposed by Wadsworth for the ultra-basic igneous rock, forming the hill. It is an aggregate of titaniferous magnetite, plagioclase, olivine and secondary minerals, but contains from 40–45 per cent. iron oxides and about 10 per cent. TiO_2. Lithological Studies, 1884.

Cumulites, Vogelsang's name for spherulitic aggregates of globulites. Die Krystalliten, 1875.

Cuselite, Rosenbusch's name for a peculiar variety of augite-porphyrite from Cusel, in the Saar basin. Massige Gest., 503, 1887.

D

Dacite, quartz-bearing andesites. The name was suggested by the ancient Roman province of Dacia, now in modern Hungary. See p. 40.

Damourite-schist, a micaceous schist whose micaceous mineral is damourite. Much the same as hydro-mica schist. See p. 101.

Desmosite, a banded contact rock developed from shales and slates by intrusions of diabase. Compare spilosite and adinole. See Zincken, Karsten und v. Dechen's Archiv., XIX., 584, 1845.

Detritus, a general name for incoherent sediments produced by the wear and tear of rocks through the various geological agencies. The name is from the Latin for "worn."

Devitrification, the process by which glassy rocks break up into definite minerals. The latter are usually excessively minute, but are chiefly quartz and feldspars.

Diabase, igneous rocks, in sheets or dikes, consisting essentially of plagioclase, augite and magnetite, with or without olivine, and possessing *ophitic* texture. See p. 44. The word has had a somewhat variable significance during its history, but with the final exit of the time-element in the classification of igneous rocks its present significance is generally accepted as above given.

Diallage, the variety of monoclinic pyroxene that, in addition to the prismatic cleavages, has others parallel to the vertical pinacoids. Used also as a prefix to many rocks containing the mineral.

Diatomaceous earth, rocks essentially formed of the abandoned frustules of the microscopic organisms called diatoms.

Dichroite, see under cordierite.

Dikes, spelled also dykes, intrusions of igneous rocks in fissures; not to be confused with veins which are precipitated from solution.

Diluvium, a name formerly applied to the unsorted and sorted deposits of the Glacial period, as contrasted with the later water sorted alluvium, which see.

Diorite, a granitoid rock consisting essentially of plagioclase and hornblende. More or less biotite is usually present, which may even replace the hornblende, yielding mica-diorite; augite also often appears. Acidic varieties with quartz are called quartz diorites. See pp. 47, 48. Diorite is often used as a prefix for porphyritic or other rocks related to diorite. The name is from the Greek to distinguish and was given by Hauy in 1822.

Dipyr, a variety of scapolite, aften used as a prefix to the names of rocks that contain the mineral.

Disthene, synonym of cyanite, sometimes used as a prefix in rock names.

Ditroite, a nepheline syenite from Ditro in Hungary, especially rich in blue sodalite. See p. 37.

Dolerite, coarsely crystalline basalts. The word has had a somewhat variable meaning during its history and among different peoples. The English use it interchangeably with diabase; indeed the definitions given here justify this usage, except that the ophitic texture of diabase is not essential to this definition of dolerite. But the ophitic texture is more of a microscopic feature than megascopic. Dolerite is from the Greek for deceptive, and was given by Hauy in allusion to its application to later rocks that could not be distinguished from older greenstones. The name is a long standing indictment of the time element in the classification of igneous rocks.

Dolomite is applied to those rocks that approximate the mineral dolomite in composition. Named by Saussure, after Dolomieu, an early French geologist. See p. 72.

Dolomitization or **Dolomization,** the process whereby limestone becomes dolomite by the substitution of magnesian carbonate for a portion of the original calcium carbonate. If the $MgCO_3$ reaches 45.65 per cent. there is great shrinkage in bulk, leading to the development of porosity and cavities up to 11 per cent. of the orignal rock.

Domite, a more or less decomposed trachyte from the Puy de Dome in the French volcanic district of the Auvergne. The typical domite contains oligoclase and is impregnated with hematite.

Drift, a general name for the unsorted deposits of the glacial period. Where subsequently worked over by water they are called modified drift.

Dunite, a member of the peridotite group that consists essentially of olivine and chromite. It was named from the Dun Mountains in New Zealand, the original locality, but it also occurs in North Carolina. The name was given by V. Hochstetter in 1859. Geol. v. Neu Seeland, 218, 1864.

Durbachite, a name give to a basic development at the outer border of a granite intrusion in Baden. It has the general composition of mica syenite. The name was given by Sauer, Mitth. d. grossh. bad. Geol. Landesanstalt, II., 233.

Dykes, see dikes.

Dynamometamorphism, a general term for those metamorphic changes in rocks that are produced by mechanical as distinguished from chemical processes, but the former are seldom unattended by the latter See p. 93.

Dysyntribite, a name given by C. U. Shepard, A. A. A. S., 1851 311, to a mineral or rock in St. Lawrence Co., N. Y., which is a hydrate silicate of aluminium and potassium, and is related to pinite; the name means hard to crush. Compare parophite. See also, Smith and Brush, Amer. Jour. Sci., II., XVI., 50, and C. H. Smyth, Jour. of Geol., II., 678, 1894.

E

Eclogite, a more or less schistose metamorphic rock, consisting of a light-green pyroxene (omphacite), actinolite (var. smaragdite) and garnet. Scarcely known in America. See p. 105 and anal. 6, p. 103. The name is from the Greek to select, in reference to its attractive appearance.

Effusive, a name applied to those rocks that have poured out in a molten state on the surface and have there crystalized, *i. e.*, volcanic rocks. See p. 13.

Elaeolite, or **Eleolite**, a name formerly current for the nepheline of pre-tertiary rocks. It is best known in the rock-name eleolite-syenite, a synonym of nepheline-syenite, which is preferable. See nepheline-syenite.

Elvan, Cornish name for dikes of quartz-porphyry or of granite-porphyry.

Endomorphic, used as a descriptive adjective for those phases of contact-metamorphism that are developed in the intrusion itself. It is synonymous with internal as used on p. 87.

Enstatite, the variety of orthorhombic pyroxene with less than 5 per cent. FeO. It is largely used as a prefix to the names of rocks that contain the mineral.

Epidiorite, a name applied to dikes of diabase, whose augite is in part altered to green hornblende. The name was coined before it was understood that the hornblende was secondary in this way. It was first applied by Gümbel in 1879 to a series of narrow dikes that cut Cambrian and Ordovician strata in the Fichtelgebirge. The name emphasizes their later age than the typical pre-Cambrian diorites, but its significance has been expanded in later years.

Epidosite, rocks largely formed of epidote. The epidote seems generally to be produced by the reactions of feldspars and bisilicates upon each other during alteration.

Epidote, the name of the mineral is often prefixed to to the names of rocks containing it. As a rule, the presence of epidote indicates the advance of alteration.

Erosion, geological term for the process of the removal of loose materials in suspension in running water or in wind.

Eruptive, the name ought properly to be only applied to effusive or volcanic rocks, but it is often used as a synonym of igneous.

Eucrite, a name given by G. Rose to rocks and meteorites that consist essentially of anorthite and augite. The term is practically obsolete. Pogg. Annalen, 1835, I., 1.

Eudyalite, the name of the mineral is sometimes prefixed to the rare nepheline syenites that contain it.

Eulysite, a name given by Erdmann to rocks interlaminated with the gneisses of Sweden, and consisting of olivine, green pyroxene and garnet. Neues Jahrb. 1849, 837.

Euphotide, the name chiefly used among the French for gabbro. It was given by Hauy, and is derived from the Greek words for well and light, in allusion to its pleasing combination of white and green.

Eurite, used among the French as a synonym of felsite, but also applied to compact rocks chiefly feldspar and quartz, such as some granulites. The name was first given by Daubuisson to the groundmasses of porphyries, because of their easy fusibility as compared with hornstone or flint.

Eutaxitic, a general name for banded volcanic rocks. The banding is due to the parallel arrangement of portions of the rock that are contrasted either in mineralogy or texture.

Exomorphic, a descriptive term for those changes produced by contact-metamorphism in the wall rock of the intrusion; the antithesis of endomorphic. It is synonymous with external as used in p. 88.

Extrusive, synonym of effusive, much used in America.

F

Feldspar, the name of the mineral is often prefixed to the names of those rocks that contain it, as feldspar-porphyry, feldspar-basalt, etc.

Feldspathoids, silicates of alumina and an alkali or alkaline earth, that are practically equivalent to feldspars in their relations in rocks. The principal ones are nepheline, leucite and melilite, but sodalite, nosean and hauyne could perhaps be also considered such, although their composition varies from the above.

Felsite, the word was first applied in 1814 by Gerhard, an early geologist, to the fine groundmasses of porphyries. These were recognized to be fusible as distinguished from hornstone, which they resembled (compare eurite). Felsite is now especially used for those finely crystalline varieties of quartz-porphyries, porphyries or porphyrites that have few or no phenocrysts, and that therefore give but slight indications to the unaided eye of their actual mineralogical composition. The microscope has shown them to be made up of microscopic feldspars, quartzes and glass. Petrosilex has been used as a synonym. See p. 24.

Felsitic has been employed as a megascopic term in the preceding pages to describe those textures which are characteristic of felsites, *i. e.*, micro-crystalline, but without phenocrysts. See p. 15. It is often used also to describe the groundmasses of truly porphyritic rocks, that are micro-crystalline, but clearly not glassy. In this sense we have felsite porphyry, felso-liparite, felso-dacite, etc.

Felspar, the current spelling of feldspar among the English. It is based on an old typographical error in Kirwan's Mineralogy, I., 317, 1794, now, however, firmly established in general usage.

Ferrite, microscopic crystals of iron oxide.

Ferrolite, Wadsworth's name for rocks composed of iron ores. Rept. State Geol. Mich., 1891–92, p. 92.

Fibrolite, synonym of sillimanite, and sometimes used as a prefix to rock names.

Fiorite, siliceous sinter, named from Mt. Santa Fiora, in Tuscany.

Firn, Swiss name for the granular, loose or consolidated ice of the high altitudes before it forms glacial ice below.

Flaser-structure, a structure developed in granitoid rocks and especially in gabbros by dynamic metamorphism. Small lenses of granular texture are set in a scaly aggregate that fills the interstices between them. It appears to have been caused by shearing that has crushed some portions more than others and that has developed a kind of rude flow-structure.

Flint, a compact and crypto-crystalline aggregate of chalcedonic and opaline silica. Chert and hornstone are synonyms. See pp. 74, 80.

Float, a term much used among Western miners for loose surface deposits, which are usually somewhere near their parent ledges.

Flow-structure, a structure due to the alignment of the minerals or inclusions of an igneous rock so as to suggest the swirling curves, eddies and wavy motions of a flowing stream. It is caused by the chilling of a flowing lava current. Fluxion-structure is synonymous.

Foliation, the banding or lamination of metamorphic rocks as distinguished from the stratification of sediments.

Forellenstein, a variety of olivine-gabbro, consisting of plagioclase, olivine and more or less pyroxene. The dark silicates are so arranged in the lighter feldspar as to suggest the markings of a trout. (German, Forelle.)

Formation, as defined and used by the U. S. Geological Survey, it is a large and persistent stratum of some one kind of rock. It is also loosely used for any local and more or less related group of rocks. In Dana's Geology it is used for the groups of related strata that were formed in a geological period.

Fourchite, a name proposed by J. Francis Williams for those basic dike rocks that consist essentially of augite in a glassy groundmass, *i. e.*, dike-augitites. The name was suggested by Fourche Mountain, Ark., where they are abundant. Ann. Rep. Geol. Sur., Ark., 1890, II., 107.

Foyaite, a name originally applied to the nepheline syenite, with supposed hornblende, of Mt. Foya, in the Monchique range of Portugal. Although the hornblende has since proved to be augite and ægirine the name foyaite is still employed for nepheline syenite with hornblende. See p. 37.

Fragmental, descriptive term for the rocks formed from fragments of preëxisting rocks, such as sandstones, breccias, clastic.

Fraidronite, a name used by early French geologists for a variety of minette.

Freestone, a quarryman's name for those sandstones that submit readily to tool treatment.

Fruchtschiefer, German name for a variety of spotted contact schists in the outer zone of the aureole. See p. 89.

Fuller's earth, a fine earth, resembling clay, but lacking plasticity. It is much the same chemically as clay, but has a decidedly higher percentage of water.

Fulgurite, little tubes of glassy rock that have been fused from all sorts of rock by lightning strokes. They are especially frequent in exposed crags on mountain tops. The name is derived from the Latin for thunderbolt.

G

Gabbro, an Italian word formerly used for a rock composed of serpentine and diallage. It was later applied to igneous rocks, of granitoid texture, consisting of plagioclase and diallage, but as now used any monoclinic pyroxene may be present with or without diallage. As the name of a group it includes those rocks with plagioclase and orthorhombic pyroxene as well, and even the peridotites from their close geological connection with the gabbros may conveniently be embraced. Although of the same mineral composition with gabbro, yet the peculiar ophitic texture of diabase may be remarked. Intermediate types have even been called gabbro-diabase. See p. 50. A full review of the meaning and history of gabbro, by W. S. Bayley, will be found in Jour. of Geology I., 435, Aug., 1893.

Gabbro-diorite, gabbro with hornblende which may, in fact, be secondary after augite. Intermediate rocks between true gabbros and diorites.

Ganggesteine, German for dike rocks.

Garnet-rock, a rock composed essentially of garnets.

Generations of minerals in an igneous rock refer to the groups of individuals that crystallize out at a definite period and in a more or less definite succession during cooling. The same species may have one, two or very rarely three generations. See p. 17.

Geodes, hollow, rounded boulders lined with crystals projecting inward from the walls.

Geyserite, siliceous deposits from a geyser. See p. 80.

Gieseckite-porphyry, a nepheline porphyry from Greenland, whose nepheline phenocrysts are altered to the aggregate of muscovite scales, which was called gieseckite under the impression that it was a new mineral. Liebenerite porphyry is the same thing from Predazzo, in the Tyrol.

Glass, the amorphous result of the quick chill of a fused lava. See pp. 20, 21, 22, and for glassy texture, p. 14.

Glauconite, the green silicate of iron and potassium that is important in many green sands. See p. 69.

Glaucophane, a blue soda-amphibole found especially in certain rare schists. See pp. 103, 105.

Gneiss, a laminated or foliated granitoid rock that corresponds in mineralogical composition to some one of the plutonic rocks. The name originated among the Saxon miners. See p. 105.

Granite, in restricted signification is a granitoid igneous rock consisting of quartz, orthoclase, more or less oligoclase, biotite and muscovite, but it is widely used in a more general sense. The first three may also be combined with either of the micas alone, with hornblende or with augite. In its technical applications as a name of a building stone it is used for almost any crystalline rock composed of silicates, as contrasted with sandstones, slates, limestones and marbles. It is a very old term. See p. 31.

Granitelle, a granite with comparatively little mica, so that it consists almost entirely of quartz and feldspar; binary granite. It has been also used by R. D. Irving for augite-granite. U. S. Geol. Surv., Monograph V., p. 115.

Granite-porphyry, practically a quartz-porphyry with a coarsely crystalline groundmass; an intermediate rock between granites and typical quartz-porphyries, having the same minerals as the former, but being porphyritic like the latter. The chief phenocrysts are, however, feldspars. See pp. 25, 32.

Granitite, a special name for biotite-granite. It is much the commonest of the granites.

Granitoid, used in preceding pages as a textural term to describe those igneous rocks which are entirely composed of recognizable minerals of approximately the same size. It was suggested by granite, the most familiar of the rocks which show this characteristic. See p. 13. In the granitoid texture each kind of mineral appears in but one generation, and the individuals seldom have crystal boundaries.

Granophyric, a descriptive term used in connection with microscopic study, to describe those groundmasses in quartz-porphyries in which the quartz and feldspar crystals have simultaneously crystallized so as to mutually penetrate one another. The several parts of one individual, though separated from one another, extinguish together between crossed nicols. See also micro-pegmatitic, micro-perthitic, micro-poicilitic, and micro-granitic.

Granulite, properly speaking a finely crystalline, laminated metamorphic rock consisting essentially of orthoclase, quartz and garnet, but having also at times cyanite, hornblende, biotite or augite. It is best developed in the mountains of Saxony. Sometimes the name is less correctly used for muscovite granite, or for granites containing little else than quartz and feldspar. See p. 98.

Graphite, the name of the mineral is often prefixed to the names of rocks containing it, as graphite-gneiss, graphite-schist, etc.

Graywacke, an old name of loose signification but chiefly applied to metamorphosed shaly sandstones that yield a tough, irregularly breaking rock, different from slate on the one hand and from quartzite on the other.

Greenschists, chlorite schists, which may, however, be of quite diverse origin. See p. 104.

Greenstone, an old field name for those compact igneous rocks that have developed enough chlorite in alteration to give them a green cast. They are mostly diabases and diorites. Greenstone is partially synonymous with trap. It is often used as a prefix to other rock names.

Greisen, a granitoid but often somewhat cellular rock, composed of quartz and muscovite or some related mica, rich in fluorine. It is the characteristic mother rock of the ore of tin, cassiterite, and is in most cases a result of the contact action of granite and its evolved mineralizers. See p. 92.

Grit, coarse sandstone.

Grorudite, Brögger's name for a porphyritic dike rock from Grorud, near Christiania, Norway. The phenocrysts are microcline and aegirine; the groundmass consists of rectangular orthoclase, quartz and aegirine. It is a variety of granite porphyry. Zeitsch. f. Krys., XVI., 65.

Groundmass, the relatively finely crystalline or glassy portion of a porphyritic rock as contrasted with its phenocrysts. Not to be confused with basis, as will be seen by referring to the latter. On groundmass, see p. 14.

Gumbo, a name current in Western and Southern States for those soils that yield a sticky mud when wet.

H

Hälleflinta, a Swedish name for dense, compact metamorphic rocks consisting of microscopic quartz and feldspar crystals, with occasional phenocrysts and sometimes hornblende, chlorite, magnetite and hematite. They are associated with gneisses, but are of obscure origin.

Haloidite, Wadsworth's name for rock-salt. Rept. State Geol. Mich., 1891–92, p. 92.

Hard-pan. See boulder-clay.

Harzburgite, a name proposed by Rosenbusch for those peridotites that consist essentially of olivine and enstatite or bronzite. Mass. Gest., 1887, 269. Saxonite was earlier proposed by Wadsworth (1884) for the same rock, and has priority.

Hauyne, the name of the mineral is often prefixed to the names of those rocks that contain it, as hauyne-basalt, hauyne-trachyte, etc.

Hedrumite, a name proposed by Brögger for certain syenitic rocks that are poor or lacking in nepheline, but that have a trachytic texture. Zeitschr. Krys., XVI., 40. They are not yet (1895) fully described.

Hemithrene, Brogniart's name, current among the French, for certain dioritic rocks that have a large amount of calcite, presumably an alteration product.

Holocrystalline, a textural term applied to those rocks that consist entirely of crystallized minerals as distinguished from those with more or less glass.

Hornblende, the name of the mineral is prefixed to many rock names.

Hornblendite, a granitoid igneous rock consisting essentially of hornblende, analogous to pyroxenite. See p. 51.

Hornfels, dense, compact rocks produced from slates by the contact action of some igneous intrusion, especially granite. Various microscopic minerals are developed in them. See p. 88.

Hornstone, synonym of flint and chert.

Horses, a miner's term for fragments of wall rock included in a vein.

Hudsonite. See cortlandite.

Hyaline, synonym of glassy and often prefixed to the name of volcanic rocks to signify a glassy development, as hyalo rhyolites.

Hyalomelane, Hausmann's name for basaltic glass. The word is derived from the Greek for black glass.

Hydato, a syllable prefixed to lithologieal terms to indicate an origin through aqueous processes.

Hydatopneumatolithic, a term used in discussions of certain ore deposits to describe their origin through the agency of water and vapors.

Hyperite, used in Sweden loosely for the rocks of the gabbro family, and in a restricted sense for olivine-norite.

Hypersthenite, a somewhat obsolete name for norite.

Hysterogenite, Posepny's term for mineral deposits of latest formation, such as those from the débris of other rocks. Trans. Amer. Inst. Min. Eng., XXIII., 211. Compare idiogenite, xenogenite.

Hysteromorphous, a term suggested by Posepny for those ore deposits that have been formed by the chemical and mechanical influences of the surface region from some other original deposits. Trans. Amer. Inst. Min. Eng., XXIII., 331, 1893.

I

Idiogenites, a term suggested by Posepny to describe those ore deposits which are contemporaneous in origin with the wall rock. The word means of the same origin. Trans. Amer. Inst. Min. Eng., XXIII., 211, 1893. Compare xenogenite, hysterogenite.

Idiomorphic, a descriptive term for those component minerals of a rock that have their own crystal faces. Rarely all are of this character, and then the rock is called panidiomorphic. Again, some are, and others are not, giving the hypidiomorphic texture. The phenocrysts of porphyries are most prone to be idiomorphic. When no minerals have their own crystal faces, as in most granites, the rock is allotriomorphic, as earlier explained. All these terms were suggested by Rosenbusch. Mass. Gesh., 1887, but Rohrbach's automorphic and xenomorphic, as is stated under the former, have a year's priority and mean the same thing. The words are of chief importance in microscopic work.

Ijolite, a granitoid nepheline rock, occurring in Finland and corresponding in mineralogy to the nephelinites. It contains chiefly nepheline and pyroxene. The name is derived from the Iijoki River, Finland, and was given by Ramsay and Berghell. Stockholm geol. fören. förh. 1891, 300.

Inclusions, the term is applied both to crystals or anhedra of one mineral involved in another, and to fragments of one rock inclosed in another, as when a volcanic flow picks up portions of its conduit.

Infusorial earth. See diatomaceous earth.

Intratelluric, a term applied to those processes that take place deep within the earth. For example, the large phenocrysts of a porphyry are usually of intratelluric crystallization. See p. 14.

Intrusive, the contrasted term with effusive, and applied to those rocks that have crystallized without reaching the surface. They therefore form dikes, laccolites and bathylites. Plutonic is, to a certain extent, synonymous. See p. 13.

Itabirite, a metamorphic rock, first described from Brazil, of schistose structure and composed essentially of quartz grains and scales of specular hematite. Some muscovite is also present. It is a close relative of itacolumite. It was named from Itabira, a place in Brazil. When it crumbles to powder it is called jacotinga.

Itacolumite, or flexible sandstone, is a peculiar quartz schist first described from Brazil, but since found in North Carolina and elsewhere.

It is composed of interlocking quartz grains, to which it owes its flexibility, of muscovite, talc and a few other minerals, and has been regarded as the mother rock of the Brazilian diamonds. See p. 107.

J

Jacupirangite, a name derived from Jacupiranga, Prov. São Paulo, Brazil, and applied by O. A. Derby to a group of igneous rocks, consisting sometimes of pure magnetite; again of magnetite with accessory pyroxene; or of pyroxene with accessory magnetite; or of pyroxene and nepheline with biotite and olivine in greater or less quantity. Amer. Jour. Sci., April, 1891, 314.

Jasper, red chalcedony, abundant enough on Lake Superior and elsewhere to be a rock.

Jaspilite, a name originally proposed by Wadsworth for all the acid eruptive rocks, whose chemical and physical condition carries them above the rhyolites, but now used more or less loosely around Lake Superior for the jasper associated with the local iron ores.

K

Kaolin, the hydrated silicate of alumina, $Al_2O_3,2SiO_2,2H_2O$, that is the base of clays, and that gives them plasticity. See p. 67.

Kelyphite-rim, a name applied by Schrauf to rims of pyroxene, hornblende and spinel that sometimes surround the garnets of peridotites. It is of microscopic application.

Keratophyr, a rock intermediate between porphyries and porphyrites, and differing from either in having as the principal feldspar, anorthoclase instead of either orthoclase or the soda lime feldspars. Keratophyr applies to pre-tertiary rocks, whereas pantellerite is used for the same aggregate of more recent geological date. The name was given in 1874 by Gümbel to certain Bavarian felsitic and porphyritic rocks that resembled hornfels, hence the name from the Greek for horn. Its significance has since been restricted.

Kersantite, a very old name of somewhat varying application, but formerly used for rocks that are intermediate between diorites or their corresponding porphyrites and gabbros or diabases. Mica-diabase was used as a synonym. Rosenbusch, in carrying out the separation of the dike rocks from the effusive and intrusive grand divisions has sought to restrict the name to those dike rocks with plagioclase that have prevailing dark silicates of which the chief is biotite. Kersanton is practically a synonym. Both names are derived from a town in Brittany.

Kies, a general term for the sulphide ores, now adopted into English from the original German.

Kieselguhr, German name for diatomaceous earth, and more or less current in English.

Killas, Cornish miner's term for the slates or schists that form the country rock of the Cornish tin veins.

Kimberlite, a name given by H. Carville Lewis to the peridotite that forms the diamantiferous dike at the Kimberley mines, of South Africa. (Geol. Magazine, 1887, 22.) The word is mis-spelled Kimberleyite on p. 51. The rock is more porphyritic than typical peridotite.

Kinzigite, a metamorphic rock consisting of biotite, garnet and oligoclase. It was named in 1860 by Fischer, from the Kinzig Valley, in the Black Forest. Neues Jahrb., 1860, 796.

Knotty, a descriptive term for those slates or schists which are so altered by contact metamorphism as to have new minerals developed in them, giving them a spotted or knotty appearance. See p. 89.

Krablite, ejected blocks from the volcano of Krafla, in Iceland, which were regarded many years ago by Forchhammer, under the name baulite, as a feldspar, of percentage in silica far beyond that of albite. (Jour. f. prakt. Chemie, 1843, 390; Jahresber. über die Fortschrit. Chemie u. Mineralogie, 1844, 262.) It was soon shown by the microscope to be an aggregate.

Kugel, the German word for ball or sphere, and often prefixed to those igneous rocks that show a spheroidal development, such as corsite, orbicular granite, etc.

Kulaite, a name derived from the Kula basin in Lydia, Asia Minor, proposed by H. S. Washington, for those rare basalts (there abundant) in which hornblende surpasses augite in amount. "The Volcanoes of the Kula Basin." Privately printed. New York, 1894, Amer. Jour. Sci., Feb. 1894, p. 115.

L

Labradorite, the name of the feldspar is prefixed to many rock names. Labradorite rock was formerly much used for anorthosite, which see.

Laccolite, a name based on the Greek word for cistern and suggested by G. K. Gilbert for those intrusions of igneous rock that spread out laterally between sedimentary beds like a huge lens, and that never reach the surface unless exposed by erosion. See p. 12; also Geology of the Henry Mountains, Utah, p. 19.

Lamprophyr, a general term, now used in a somewhat wider sense than as originally proposed by Gümbel, who suggested it. Rosenbusch, in the Massigen Gesteine, gave it its present significance. Lamprophyrs are dike rocks of porphyritic texture, whose predominant phenocrysts are the dark silicates, augite, hornblende or biotite. They are practically basic dikes. The word means a shining rock, and was first applied in 1874 to small dikes in the Fichtelgebirge that were rich in biotite.

Lapilli, volcanic dust and small ejectments, the results of explosive eruptions.

Lassenite, Wadsworth's name for unaltered glassy trachytes. Rept. State Geol. Mich., 1891–92, p. 97. The name is derived from Lassen's Peak, Cal.

Laterite, a name derived from the Latin word for brick earth, and applied many years ago to the red, residual soils or surface products that have originated in situ from the atmospheric weathering of rocks. They are especially characteristic of the tropics. Though first applied to altered basaltic rocks in India, laterite has had in later years a general application without regard to the character of the original rock. Compare saprolite. See pp. 116, 117.

Laurdalite, a name given by Brögger to a coarsely crystalline variety of nepheline-syenite, that is abnormal in having for its feldspar natron-orthoclase, rarely natron-microcline, instead of the normal potash orthoclase. The dark silicates are biotite, diallage and olivine. Zeitsch., f. Kryst., XVI., 28, 1890.

Laurvikite, a name applied by Brögger to a Norwegian variety of augite-syenite that contains natron-orthoclase as its chief feldspar and most abundant mineral. The other components are rare plagioclase, pyroxene, biotite, barkevicite or arfvedsonite, olivine and magnetite. Besides microscopic accessories, nepheline is occasionally met. Zeitsch., f. Kryst., XVI., 29, 1890. Compare pulaskite.

Lava, a general name for the molten outpourings of volcanoes.

Laxite, Wadsworth's name for the fragmental or mechanical rocks, especially when unconsolidated. Rept. of State Geol. of Mich., 1891–92, p. 98.

Leopardite, a siliceous rock from North Carolina, spotted with stains of manganese oxide. It is usually considered to be a quartz-porphyry.

Leopard rock, a local name in Canada, applied to pegmatitic rocks which are associated with the apatite veins of Ontario and Quebec. See C. H. Gordon, Bulletin Geolog. Society of America, VII., 122.

Leptinite or **Leptynite**, the French synonym of granulite as used among the Germans. See granulite.

Leucite-basalt, basaltic rocks with olivine in which leucite replaces plagioclase. See p. 44.

Leucite-basanite, basaltic rocks that contain both leucite and plagioclase. As contrasted with leucite-tephrites, they contain olivine. See p. 44.

Leucitite, basaltic rocks without olivine in which leucite replaces plagioclase. Compare leucite-basalt.

Leucitophyre, a name formerly used as a general one for the leucite rocks, but now by common consent restricted to those phonolites that contain both leucite and nepheline.

Leucite-tephrite, basaltic rocks without olivine, that contain both plagioclase and leucite. Compare leucite-basanite.

Leucophyre, originally applied by Gümbel in 1874 to light-colored diabases whose feldspar was altered to saussurite and whose augite had largely changed to chlorite. Rosenbusch restricts it to diabases poor in plagioclase. The name means a light-colored or white porphyritic rock, and has little claim to consideration either in etymology or application.

Lherzolite, a variety of peridotite, first discovered in the Pyrenees, and containing olivine, diopside and an orthorhombic pyroxene. Much picotite is also present. It is named from Lake Lherz, by de la Méthèrie, Theorié de la Terre, II., 281.

Liebenerite-porphyry, nepheline-porphyry whose nepheline phenocrysts are altered to muscovite. Its original locality is near Predazzo, in the Tyrol. Compare gieseckite-porphyry.

Limburgite, porphyritic basaltic rocks consisting of olivine and augite in a glassy groundmass. They lack feldspars. See p. 45. The name is derived from Limburg, a locality on the Kaiserstuhl, a basaltic mountain in Baden. It was suggested by Rosenbusch in 1872, and at the same time Boricky described similar rocks from Bohemia as magma-basalt.

Limestone, the general name for rocks composed essentially of calcium carbonate. See p. 71.

Lindöite, Brögger's name for certain dike rocks, in the region of Kristiania. They have trachytic texture; are seldom and then but slightly porphyritic; are medium to coarsely crystalline in the larger dikes; possess light colors; and often lack dark colored minerals. When such are recognizable they are pyrite and chlorite. Ferriferous carbonates are present. Traces of ægirine and of a dark alkali hornblende may be occasionally detected. (Die Eruptivgesteine des Kristianiagebietes, I., 131, 1894.)

Liparite, a synonym of rhyolite, and largely used for the latter among Europeans, though rhyolite is chiefly current in America and England. The name is derived from the Lipari Islands, off the coast of Italy, where the rocks are abundant. It was proposed by Justus Roth in 1861. Gesteins-analysen, p. xxxiv.

Litchfieldite, a name proposed by W. S. Bayley for the variety of nepheline-syenite occurring in loose boulders near Litchfield, Me., whose chief feldspar is albite and which differs therefore from normal nepheline-syenite. Bull. Geol. Soc. Amer., III., 243.

Lithical, a term proposed by L. Fletcher for the finer textural characters of rocks, *i. e.*, those for which texture as distinguished from structure is employed above. See p. 13. Lithical from the Greek for stone is contrasted with petrical from the Greek for rock. Introduction to the Study of Rocks; British Museum Handbooks, 1895.

Lithionite-granite, a name proposed by Rosenbusch for granites with lithia mica or lithionite.

Lithographic limestone, an exceptionally homogeneous and fine-grained limestone, suitable for lithography.

Lithoidal, a descriptive term applied to those groundmasses, especially of rhyolites, that are excessively finely crystalline, like porcelain, as distinguished from glassy varieties. The English equivalent, stony, is also used.

Lithophysæ, literally "stone bubbles," a name applied to those cellular cavities in acidic lavas, obsidian, rhyolite, etc., that have concentric walls and that are caused by a special development of mineralizers at that particular point. They are usually hemispherical in shape and on the walls may have various well crystallized minerals. See p. 22.

Lithosphere, the outer stony shell of the earth. See barysphere.

Local metamorphism, *i. e.*, contact metamorphism. See p. 85.

Loess, fine surface soils chiefly formed of wind-blown dust. See p. 65. The name is a German word, akin to loose, and appears to have been first applied geologically in the Rhine valley.

Luciite, Chelius' name from the Luciberg in Hesse, for finely crystalline diorite dikes whose minerals are xenomorphic. Notizblatt Verein. f. Erdkunde, Darmstadt, 1892, 1.

Luijaurite, a name proposed by Brögger for a nepheline syenite, rich in ægirine and eudialyte. Zeitsch. f. Kryst., XVI., 204. The name is from a Lapland locality, where the rock was discovered by Ramsay.

Lustre-mottlings, a name applied by Pumpelly to certain augitic rocks which have a shimmering lustre because the shining cleavage faces of the augite crystals are mottled by small inclusions. Proc. Amer. Acad., XIII., 260, 1878. Compare poicilitic and schiller.

Luxullianite, a tourmaline granite from Luxullian, in Cornwall, that is a product of contact metamorphism. See p. 32.

Lydite. See basanite.

M

Macroscopic, a word formerly current as a synonym of megascopic, *i. e.*, recognizable by the naked eye. It is etymologically less correct as an antithesis of microscopic than is megascopic, for "macro" is from the Greek for broad, whereas "mega" means large. Nevertheless, it preceded megascopic in general use and is still current.

Magma is now generally employed for the molten masses of igneous rock before they have crystallized. An original parent magma may break up into several derived ones. See pp. 2, 13, 57. The word is also used in the sense of basis as earlier defined, but this use is unfortunate.

Magma-basalt, a synonym of limburgite, which was proposed by Boricky, in 1872, at about the same time that Rosenbusch suggested limburgite. Some authorities give the former the preference.

Magnetite. The name of the mineral is prefixed to the names of many rocks in which it is prominent. It almost furnishes a rock itself, at times.

Malchite, a variety of diorite dikes which have in a groundmass of quartz, feldspar and hornblende, phenocrysts of plagioclase, hornblende and biotite. The name was given by A. Osann, and is derived from Malchen, another name for Mt. Melibocus, in Hesse.

Malignite, a name proposed by Lawson for a group of rocks on the Maligne river, Rainy Lake district, province of Ontario. They are described as "basic, holocrystalline, plutonic rocks, rich in alkalies and lime." Iron is present in moderate amounts almost entirely combined in the silicates. Iron and magnesia are more abundant than is usual in the alkali-rich plutonic rocks. The chief minerals are orthoclase, often microscopically intergrown with an acid plagioclase; ægerine-augite, which may predominate with but a moderate admixture of biotite, or may be subordinate and intergrown with preponderant soda amphibole, biotite being present as before. There are three types of malignites, one of which has much melanite and another much nepheline. Bull. Dept. Geol. Univ. Calif., I., 340, 1896.

Manganolite, Wadsworth's name for rocks composed of manganese minerals, such as wad, psilomelane, etc. Rept. State Geol. Mich., 1891–92, p. 93.

Marble, in lithology, a metamorphosed and recrystallized limestone. In the trade the name is applied to any limestone that will take a polish.

Marekanite, a rhyolitic perlite from the banks of the Marekana River, near Ochotsk, Siberia. At times a very clear glass, it is found in balls and as cores of large perlitic masses and may even be under strain like Prince Rupert's drops. See Zirkel's Petrographie, II., 299.

Marl, a calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells. Marl in America is chiefly applied to incoherent sands, but abroad compact impure limestones are also called marls.

Marmarosis, the general name for the process of crystallization of limestone to marble, whether by contact or regional metamorphism. It was coined by Geikie from the Latin for marble.

Massive, the antithesis of stratified and therefore often used as a synonym of igneous or eruptive rocks as contrasted with the sedimentary and laminated metamorphic.

Megascopic, a descriptive term meaning large enough to be distinguished with the naked eye; the antithesis of microscopic. See macroscopic. Used also to describe methods of observation without the microscope or with the eye alone.

Melaphyre, a rock name first introduced by Brogniart in 1813, practically for porphyritic rocks with a dark groundmass and feldspar phenocrysts. After having had various meanings for many years, by common consent, it is now generally used as suggested by Rosenbusch for pretertiary olivine-basalts, that is, for porphyritic equivalents of olivine-diabase.

Melilite-basalt, a rare basaltic rock whose feldspathoid is melilite. It was first identified by Stelzner in 1882. The rock is excessively basic. See p. 45. Alnoite is the same rock in dikes.

Mesostasis, a synonym of basis suggested by Gümbel.

Metabolite, Wadsworth's name for altered, glassy trachytes, of which lassenite is the unaltered form. Rept. State Geol. Mich., 1891–92, p. 97.

Metachemical metamorphism, Dana's term to describe that variety of metamorphism that involves a chemical change in the rocks affected. Amer. Jour. Sci., July, 1886, p. 69.

Metadiabase, a shortened form of metamorphic diabase, suggested by Dana for certain rocks simulating diabase, but supposed to have been produced by the metamorphism of sediments. Amer. Jour., Sci., Feb., 1876, 121. Compare Pseudo-diabase.

Metadiorite, dioritic rocks produced as just described under metadiabase. Compare Pseudo-diorite.

Metamorphism, a collective term for the processes by which rocks undergo alteration of all sorts. It is more fully set forth on page 84.

Metasomatic, *i. e.*, a change of substance; it is used to describe the replacement of one or more of the minerals of a rock by others. The form of the originals is not at all preserved as in pseudomorphs, nor does the chemical composition remain the same while the form alters as in paramorphs, but both customarily change. The term is especially used in connection with the origin of ore deposits. The corresponding noun is metasomatosis, but replacement is a good English equivalent.

Metaxite, a name of Hauy's for micaceous sandstone.

Mezo or **Meso** is sometimes prefixed to the names of igneous rocks of Mesozoic age.

Miarolitic, a descriptive term applied to those granites that have small cavities, into which well-terminated crystals project. See p. 13.

Miascite, a name coined from Miask, a locality in the Urals where a nepheline syenite occurs whose dark silicate is biotite. Used also as a general name for biotitic nepheline syenites. See p. 37.

Mica-schist, finely laminated metamorphic rocks, consisting of quartz, mica, feldspar and several minor minerals. See p. 99.

Mica-peridotite, a name applied by J. S. Diller to a peculiar peridotite, occurring as a dike in Crittenden County, Ky., and consisting chiefly of altered olivine and biotite. Amer. Jour. Sci., Oct. 1892, 288. See Analysis 19, p. 49.

Mica-trap, an English field name for dark dike rocks rich in mica.

Micro-felsite, a name used in microscopic work for those varieties of groundmass that do not affect polarized light, but that are not true glasses because they have a fibrous, a granular or some such texture. The textures are no doubt the result of devitrification of a glassy base in many cases.

Micro-granite, a name used in microscopic work for those groundmasses of quartz-porphyries that consist of small quartz and feldspar crystals with granitoid texture, *i. e.*, of about the same size and usually without crystallographic boundaries. See granophyric.

Micro-granulite, the French equivalent of granophyric, as earlier explained.

Micro-crystalline, granular rocks, whose components are recognizable, but so small as to require the microscope for their identification.

Microlites, generally used for microscopic, but still identifiable minerals.

Micropegmatite, *i. e.*, microscopic pegmatite, a term applied to those groundmasses of quartz-porphyries whose microscopic quartz and feldspars mutually penetrate each other. The several parts of the same crystal, though isolated, extinguish together. See granophyric.

Microperthite, *i. e.*, microscopic perthite, a term applied to that variety of orthoclase which is thickly set with flat spindles of albite. It is very common in gneisses. Compare granophyric.

Micropoikilitic, a structural term suggested by G. H. Williams to describe those minerals that are speckled with microscopic inclusions of other minerals, having no definite relations to each other or to their host. Jour. of Geology, I., 176, 1893. Poikilitic is often spelled poicilitic or poecilitic.

Millstone-grit, an old English name for the conglomeratic sandstone at the base of the Carboniferous Coal Measures. It is more or less current in this country as a synonym of the Great, Pottsville or Seral conglomerate.

Mineralizers, the dissolved vapors in an igneous magma, such as steam, hydrofluoric acid, boracic acid and others, that exert a powerful influence in the development of some minerals and textures. See p. 15. The word is also technically used in some definitions of ore. Thus it is said that an ore is a compound of a metal and a mineralizer, such as copper and sulphur, iron and oxygen, etc.

Minette, a variety of mica-syenite, usually dark and fine-grained, occurring in dikes. See p. 35, Anal. 6.

Moldauite, a very pure glass, from the valley of the Moldau river, Bohemia See bouteillenstein.

Monchiquite, a name suggested by Hunter and Rosenbusch from the Monchique Mountains, of Portugal, for basaltic dikes corresponding in mineralogy and texture to limburgite. They often accompany nepheline-syenite. Tsch. Mitt., XI., 445, 1890.

Monzonite has usually been considered as a variety of augite-syenite that displayed, however, considerable mineralogical variety. Brögger has recently used the name for a transitional and intermediate group of granitoid rocks between the granite-syenite series (*i. e.*, the alkali-feldspar series) and the diorites (*i. e.*, the lime-soda feldspar series). The monzonites have both alkali-feldspar (or orthoclase) and lime-soda feldspar (or plagioclase) in approximately equal amounts, or at least both richly. (Die Eruptivgesteine des Kristianiagebietes, II., 21, 1895.)

Mortar-structure, a term suggested by Törnebohm to describe those granites, gneisses or other rocks that have been dynamically crushed, so that larger nuclei of their original minerals are set in crushed and comminuted borders of the same, like stones in a wall.

Mulatto, a local name in Ireland for a cretaceous green sand.

Muscovado, the Spanish word for brown sugar, used by Minnesota geologists for the rusty, brown, outcropping rock that resembles brown sugar. It has been applied to both gabbros and quartzites. XVI., Ann. Rept., Minn. Geol. Surv.

Mylonite, a name suggested by the English geologist Lapworth for schists produced by dynamic metamorphism. Rept. of Brit. Assoc., 1885–86, p. 1025.

N

Nadel-diorite, *i. e.*, needle-diorite, a German term for diorites with acicular hornblende.

Napoleonite, a synonym of corsite.

Natron-granite, granites abnormally high in soda, presumably from the presence of an orthoclase rich in soda, or of anorthoclase. They are also called soda-granites. Natron is also used as a prefix to minerals and rocks that are rich in soda, as natron-orthoclase, natron-syenite, etc.

Navite, Rosenbusch's name for pre-tertiary porphyritic rocks, consisting of plagioclase, augite and olivine as phenocrysts, with a second generation of the same forming the holocrystalline groundmass. The name is from Nava, a locality in the Nahe Valley, Mass. Gest., 1887.

Necks. Lava-filled conduits of extinct volcanoes, exposed by erosion.

Nepheline-basalt, an old general name for basaltic rocks with nepheline, but now restricted to those that practically lack plagioclase, and that have nepheline, augite, olivine and basis. See p. 44.

Nepheline-basanite, basaltic rocks with plagioclase, nepheline, augite, olivine and basis. Compare nepheline tephrite. See p. 44.

Nephelinite, basaltic rocks consisting of nepheline, augite and basis, but without olivine. See p. 44.

Nephelinitoid, Boricky's term now used in microscopic work for nepheline-glass, or the glassy basis in nepheline rocks, whose easy gelatinization indicates its close relations with this mineral; unindividualized nepheline.

Nepheline-syenite, *i. e.*, eleolite-syenite, a name to be preferred to the latter as there is no real need of the word eleolite. Granitoid rocks consisting of orthoclase, nepheline, and one or more of the following: hornblende, augite and biotite. The rocks result from magmas especially rich in alkalies, and possess great scientific interest on account of their richness in rare, associated minerals. See p. 36.

Nephelite, a later method of spelling nepheline and one consistent with approved mineralogical orthography.

Nevadite, a name coined by von Richthofen from Nevada, for those rhyolites that approximate a granitoid texture, *i. e.*, with little groundmass. Mem. Calif. Acad. Sci., I., p. 54, 1867. See p. 24 and Hague and Iddings, Amer. Jour. Sci., June, 1884, 461.

Névé, a French synonym of firn.

Nonesite, porphyrites with orthorhombic pyroxene. The name was given by Lepsius. Das westliche Süd-Tyrol, Berlin, 1878.

Nordmarkite, Brögger's name for a variety of granitic rocks consisting of orthoclase, some oligoclase, more or less microperthite, quartz and somewhat subordinate biotite, pyroxene, hornblende and ægirine. It is chemically high in silica and the alkalies. Zeitsch. f. Kryst., XVI., 54, 1890.

Norite, rocks of the gabbro family that consist of plagioclase and orthorhombic pyroxene, usually hypersthene. The name has had a variable history and was originally proposed in 1832 by Esmark for aggregates of feldspar and hornblende which were lacking or notably poor in diallage and hypersthene. But as many localities were cited in later years which on microscopic examination were found rich in these minerals, Rosenbusch finally gave the name its above definition and this is its generally accepted signification.

Normal metamorphism, *i. e.*, regional metamorphism. See p. 402.

Normal-pyroxenic, Bunsen's name for his assumed typical basic igneous magma with 48 per cent. SiO_2 as contrasted with the corresponding *normal-trachytic* one with 76 per cent. SiO_2. He sought to explain all intermediate rocks by the intermingling of these two. Although apparently applicable at times and serviceable in their day, the conceptions have long since been exploded. See J. Roth's Gesteinsanalysen, 1861.

Nosean. The name of the mineral is often prefixed to the names of rocks containing it.

Novaculite, excessively fine grained quartzose rocks supposed to be of sedimentary origin from siliceous slimes. They are especially developed in Arkansas, and are much used as whetstones. See p. 64.

O

Obsidian, a general name for volcanic glass. When used alone it implies a rhyolite-glass, but it is now much employed with a prefix as andesite-obsidian, basalt-obsidian. See p. 21.

Ocellar-structure, a microscopic term used by Rosenbusch for peculiar aggregates of small pyroxenes that resemble eyes, buds and the like, and that are especially common in nepheline and leucite rocks. Mass. Gest., 625, 1887.

Odinite, a name given by Chelius to certain porphyritic dikes in Mt. Melibocus which have a groundmass of plagioclase and hornblende rods, with phenocrysts of plagioclase and augite. Notizbl. Ver. Erdkunde, Darmstadt, 1892, Heft 13, p. 1.

Olivine. The name of the mineral is prefixed to the names of many rocks that contain it. It is of especial importance in this respect, as its presence marks a more basic development in many rocks as contrasted with their varieties that lack it.

Oolitic, a textural term for those rocks that consist of small concretions, analogous to the roe of fish. Oolites are calcareous, siliceous and ferruginous.

Opacite, a noncommittal microscopic term, less current than formerly, for minute opaque grains observed in thin sections of rocks. They are generally regarded to-day as chiefly magnetite dust.

Ophicalcite, Brogniart's name for crystalline limestones, spotted with serpentine. See p. 113.

Ophiolite, Brogniart's name for the serpentines. See p. 113. It is also employed in America in the sense of ophicalcite as above given.

Ophite, a name given in 1798 by the Abbé Palassou to a green rock of the Pyrenees. It was later recognized to be composed of feldspar and hornblende, and still later was determined by Zirkel to be a uralitized diabase. The name has chief significance to-day because used to describe the textural peculiarity of diabase. An ophitic texture is one in which rod-like or lath-shaped, automorphic plagioclase feldspars form an interlaced aggregate, in whose interstices are xenomorphic augites and magnetites. The significance of it is that the feldspars crystallized before the augite, contrary to the usual succession. See p. 44 and p. 17.

Orbicular, a textural term for those rare rocks whose minerals have a spheroidal grouping, such as corsite and orbicular granite. See kugel and spheroidal.

Orbite, a name proposed by Chelius for certain diorite dikes near Orbeshöhe, Hesse, of porphyritic texture and having large phenocrysts of hornblende, biotite and plagioclase. Notizbl. Ver. Erd. Darmstadt, 1892, 1.

Orthoclase. The name of the mineral is often prefixed to the names of rocks that contain it.

Orthophyre, *i. e.*, orthoclase porphyry or porphyry proper.

Ortlerite, a name given by the Austrian geologists, Stache and von John, to certain porphyrites of the eastern Alps that resemble the old greenstones and that have plagioclase, hornblende, generally augite, and more or less basis. They range from 48–54 SiO_2. Jahrb. k. k. g[illegible] Reichsanst, 1879, 342.

Ottrelite schists, schistose rocks with the peculiar micaceous minera[illegible] ottrelite. They are best known from the Ardennes, Belgium, but ar[illegible] found in New England.

Ouachitite (pronounced wâw-shee-tite), a name coined by Kem[illegible]p from the Ouachita River, Arkansas, for certain basic dikes containing, i[illegible]n a glassy groundmass, prevailing and often phenomenally large phenocryst[illegible]ts of biotite, very subordinate augite and magnetite. They also occur a[illegible]at Beemerville, N. J., associated with nepheline syenite. Ann. Rep. Geol[illegible]ol. Surv. of Ark., 1890, II., 393.

P

Paisanite, a name proposed by Osann from the Paisano Pass, on th[illegible]h Southern Pacific R. R., in western Texas, for a variety of quartz-por[illegible] phyry, consisting of microperthitic orthoclase and rarer quartz pheno[illegible] crysts, in a groundmass of quartz and feldspar. Occasional groups o[illegible] small hornblendes (riebeckite) are met. Tscherm. Min. u Petr. Mitth.[illegible] XV., 435.

Palæophyre, Gümbel's name given in 1874 to certain porphyriti[illegible] dike rocks corresponding to quartz-mica-diorites in mineralogy. The[illegible] cut the silurian strata of the Fichtelgebirge.

Palæophyrite, a name proposed by Stache and von John (compar[illegible] ortlerite) for certain porphyrites in whose strongly prevailing groundmas[illegible]a are phenocrysts of plagioclase, hornblende and augite. Jahrb. d. k. k. g[illegible] Reichsanstalt, 1879, 342.

Palæopicrite, a name proposed by Gümbel in 1874, in his pape[illegible]er "Die palæolithischen Eruptiv-gesteine des Fichtelgebirges," a contrib[illegible]u- tion to which we are indebted for a great number of useless and unnece[illegible]es- sary rock names, for picrites regarded by him similar to those original[illegible]*ly* named by Tschermak from cretaceous strata, but which were called palæopicrites because occurring in palæozoic strata. He regarded them as aggregates of olivine, enstatite, chrome-diopside and magnetite, but they are now known to be chiefly olivine and augite. More or less brown hornblende and biotite also occur.

Palagonite-tuff, an altered basaltic tuff from Palagonia, in Sicily. The name palagonite was originally applied to problematical, brown inclusions in the tuff which were thought at first to be a definite mineral. They are now known to be a devitrified basaltic glass. The name was given by v. Waltershausen in 1846. See Vulk. Gesteine in Sicilien und Island, 1853, 179.

Palatinite, a name proposed by Laspeyres for certain rocks in the German province of Pfalz, supposed by him to be gabbros with diallage and of carboniferous age; but they have since been shown to be essentially diabases. Neues Jahrb, 1869, 516. The word is derived from the classic name of the district.

Pallasite, originally proposed by Gustav Rose for a meteorite that fell near Pallas, in Russia, it has been used by Wadsworth in a wider sense for both meteoric and terrestrial, ultra basic rocks, which in the former average about 60 % iron, and in the latter have at least more iron oxides than silica. Cumberlandite (which see) is the chief example. Lithological Studies, 1884, 68.

Panidiomorphic, Rosenbusch's term for those rocks, all of whose components possess their own crystal boundaries.

Pantellerite, a group ot rocks intermediate between the rhyolites and trachytes on the one hand and the dacites on the other. They differ from all these in having anorthoclase as the principal feldspar. Cossyrite, a rare and probably titaniferous amphibole, occurs in the original locality on the island of Pantelleria, in the Mediterranean. See p. 27. The name was given by Foerstner. Zeitschr. f. Kryst., 1881, 348.

Paragenesis, a general term for the order of formation of associated minerals in time succession, one after the other. To study the paragenesis is to trace out in a rock or vein the succession in which the minerals have developed.

Paramorphism, the passage of one mineral into another without change of composition, as augite into hornblende in uralitization. It is also used in connection with metamorphism to describe such thorough changes in a rock that its old components are destroyed and new ones are built up.

Parophite, a name given by T. Sterry Hunt, Geol. Surv. Can., 1852, 95, to a rock or mineral similar to dysyntribite. The name means like serpentine.

Pearl-diabase, see variolite.

Pearlite or **Pearlstone**, volcanic glass with concentric, shelly texture and usually with a notable percentage of water. See p. 21.

Pegmatite, originally applied to graphic granite, but of later years used as a general name for very coarse dike or vein granites, such as have large quartz, feldspar, muscovite, biotite, tourmaline, beryl and other characteristic minerals, and are often called giant-granite. See p. 31.

Pele's Hair, a fibrous basaltic glass from the Sandwich Islands, named after a local heathen goddess.

Pelite, a general name for mud rocks, *i. e.*, shales, clays and the like.

Pencatite, see predazzite.

Peridotite, granitoid rocks consisting of olivine and pyroxene with no feldspar. See p. 51. Many varieties have been made depending on the kind of pyroxene present, or on its absence in favor of related minerals, viz:

Olivine, augite—Picrite.
Olivine, diopside (diallage), enstatite—Lherzolite.
Olivine, enstatite—Saxonite, harzburgite.
Olivine, enstatite, augite—Buchnerite.
Olivine, augite, garnet—Eulysite (metamorphic ?).
Olivine, diallage, hornblende—Wehrlite.
Olivine, hornblende—Cortlandtite.
Olivine, biotite—Mica-peridotite.
Olivine, hornblende (secondary ?), biotite—Scyelite.
Olivine, alone or with chromite—dunite.

Further particulars about each of these will be found under the individual names. Compare also kimberlite.

Perthite, a name given by ~~T. Sterry Hunt~~ Thomson (Phil. Mag. 1843. 188), to parallel intergrowths of orthoclase and albite, originally described from Perth, Ontario.

Petrical. L. Fletcher's name for the coarser structural features of rocks. See lithical.

Petrography, properly the descriptive part of the science of rocks for which the more general name is petrology or lithology, but petrography is widely used as a synonym of the latter.

Petrosilex, an old name for extremely finely crystalline porphyries and quartz-porphyries and for those finely crystalline aggregates we now know to be devitrified glasses; also for the groundmasses of the former which though not glassy are yet not resolvable by the microscope into definite minerals. See felsite, micro-felsite. It was practically a confession by the older petrographers that they did not know what the rock consisted of.

Phenocrysts, a name suggested by J. P. Iddings (Bull. Phil. Soc. Wash., XI., 73, 1889), for porphyritic crystals in rocks. It has proved an extremely convenient one, although its etymology has been criticised. It may be best to change to phanerocryst, just as in botany phenogam has yielded to phanerogam; but one form or the other is an absolute necessity.

Phonolite, volcanic rocks, of porphyritic or felsitic texture, consisting of orthoclase, nepheline, pyroxene and more rarely amphibole. Leucite may replace the nepheline yielding leucite-phonolites. See p. 28. The name is Klaproth's rendering into Greek of the old name clinkstone. Abhandl. Berlin Akad., 1801.

Phosphorite, massive calcic phosphate, of the composition of apatite but usually lacking crystal form.

Phosphorolite, Wadsworth's name for phosphatic rocks, guano-phosphorite, apatite, etc. Rept. State Geol. Mich., 1891–92, p. 93.

Phthanite, Hauy's name for silicious schists. Its use has recently been revived in America by G. F. Becker, who applies it to certain silicified shales in California. Quicksilver Deposits of the Pacific Coast, Mono., XIII., 105, U. S. Geol. Survey.

Phyllite, intermediate rocks between the mica-schists and slates, usually finely crystalline; mica-slates. See p. 101.

Phyre. The last syllable of porphyry, often used with other prefixes, as vitrophyre, orthophyre, granophyre, etc.

Picrite, a name originally given by Tschermak to certain porphyritic rocks from the Carpathians, that have abundant and large phenocrysts of olivine, with less pyroxene, hornblende and biotite, in a glassy groundmass, more or less devitrified. The rocks are practically pretertiary limburgites. Picrite is now also applied to those peridotites that consist of olivine and augite. It is derived from the Greek for bitter in allusion to the high percentage of magnesia, Bittererde in German.

Pistazite, a synonym of epidote, more current in Europe than America, and used in rock names for epidote.

Pitchstone, a glassy rock, usually corresponding to the rhyolites or trachytes, but with a considerable percentage of water, 5–8% for example. It was formerly specially used for pretertiary glasses, *i. e.*, the glasses of quartz-porphyries and porphyries, but time distinctions are obsolete. Pitchstones have a marked resinous luster as the name implies. See p. 21.

Plutonic, a general name for those rocks that have crystallized in depth, and have therefore assumed as a rule, the granitoid texture. See p. 13.

Pneumatolitic, a general name for those minerals which have been produced in connection with igneous rocks through the agency of the gases or vapors called mineralizers. They may be in the igneous mass itself or in cracks in the wall rock. Compare the cases cited on pp. 91–92. The term is much used in discussions of ore deposits.

Poicilitic, *i. e.*, speckled, a term proposed by G. H. Williams for those rocks which have a mottled luster, because on the shining cleavage faces of some of their minerals, small inclusions of others occur, producing the effect. The same thing was earlier called "luster-mottling" by Pumpelly, but poicilitic has proved a useful term both in megascopic and microsopic work. (Journal of Geology, I., 176, 1893.) It is also spelled poikilitic.

Porcellanite, fused shales and clay, that occur in the roof and floor of burned coal seams. The rock is quite common in the lignite districts of the West, where apparently spontaneous combustion has fired the seams in the past.

Porodine, Breithaupt's name for amorphous rocks, such as are derived from gelatinous silica.

Porodite, Wadsworth's name proposed in 1879, for all the altered fragmental forms of eruptive rocks, commonly called diabase tuff, schalstein, etc. Bull. Mus. Comp. Zoöl., 1879, V., 280.

Porphyrite, a porphyritic rock, belonging to the plagioclase series and corresponding in mineralogy to the diorites. To distinguish it from andesite it is necessary to draw a contrast between surface flows (andesites) and intruded dikes or sheets, (porphyrites); or between tertiary and later lavas (andesites) and pre-tertiary ones (porphyrites); or between those with glassy or very finely crystalline groundmasses (andesites) and those with groundmasses of moderate coarseness (porphyrites).

Porphyritic, a textural term for those rocks which have larger crystals (phenocrysts) set in a finer groundmass, which may be crystalline or glassy, or both. See p. 13. Rosenbusch has sought to define it as the texture due to the recurrence of the period of crystallization of the same or similar minerals (Neues Jahrb., 1882, II., 3). While except for porphyritic rocks with a glassy groundmass this practically amounts to the same thing as the textural definition just given, it is idle for any writer to try to change so old, well-established and indispensable a conception.

Porphyry, a word derived from the classic name of the shell fish, a species of Murex, that yielded the Tyrian purple of the ancients. It was later applied to the red porphyritic rock of the Egyptian quarries, "porfido rosso antico," whose red color is due to piedmontite, a manganese epidote. In course of time it was applied to all porphyritic rocks as we now understand the term. In its restricted sense it implies orthoclase-porphyry, the porphyritic rock corresponding to syenite, but to give it any essential significance as contrasted with trachyte, one of the three distinctions must be drawn, which are cited above under porphyrites, and of which the second is of no real value. See p. 24. Porphyry is colloquially used for almost every igneous rock in the West, that occurs in sheets or dikes in connection with ore bodies.

Porphyroid, metamorphic rocks with porphyritic texture, *i. e.*, with phenocrysts of feldspar or other minerals in a finer groundmass, yet shown by geological relations to be altered sediments, or tuffs. Fossil remains have even been detected in some. They are close relatives of hälleflintas.

Pozzuolane, a leucitic tuff, found near Naples and used for hydraulic cement.

Predazzite, a contact rock produced at Predazzo in the Tyrol by an intrusion of syenite in crystalline dolomite. It is part calcite and part brucite or hydromagnesite. Pencatite is the same aggregate, darkened by grains of pyrrhotite.

Primary, an old synonym of Archean. Also used for those rocks which have crystallized directly from fusion or solution, as contrasted with transported or secondary sediments.

Propylite, a name given by von Richthofen in 1867 to certain andesites, formed at the beginning of tertiary time, that were thought to resemble the old diorites, and diorite-porphyrites. They had been previously called by him greenstone-trachytes in Hungary, but were not named propylite until he met them again in Nevada and California (Memoirs of the California Academy of Sciences, I., 60, 1867). The western propylites have been since conclusively shown by several American petrographers to be only more or less altered andesites. The literature of the name furnishes an interesting and amusing exhibition of the efforts of those petrographers who are influenced by the time-myth in the classification of igneous rocks to draw distinctions where there are no differences. The name means before the gates, alluding to their position at the beginning or entrance to the tertiary, which was supposed to usher in the true volcanic eruptions of geological time. See p. 41.

Proteolite, an old name for certain contact rocks produced by granite intrusions from slates in Cornwall. It has been lately revived by Bonney for andalusite-hornfels. (Q. J. G. S., 1886, 104.) Compare Cornubianite.

Proterobase, originally applied by Gümbel, 1874, to Silurian or earlier diabases with hornblende. The frequency of the paramorphism of augite to hornblende has led others to apply it to diabases with uralitized augite. Rosenbusch restricts it to diabases with original hornblende.

Protogine, an old name for a granite or gneiss in the Alps, consisting of quartz, orthoclase and chlorite or sericite, which was formerly erroneously taken for talc. The laminated structure from dynamic metamorphism is often pronounced.

Psammite, a general name for sandstones, from the Greek word for a grain of sand.

Psephites, a general name for conglomerates and breccias, *i. e.*, coarse fragmental rocks as contrasted with psammites and pelites. The name is derived from the Greek for pebble.

Pseudo-diabase, a name proposed by G. F. Becker for certain metamorphic rocks in the coast ranges of California that have been derived from sediments yet that have the minerals and texture of diabase. Monograph, XIII., U. S. Geol. Surv., p. 94. Compare Metadiabase, which means the same thing and has precedence.

Pseudo-diorite, dioritic rocks produced as described under pseudodiabase above. See the same reference.

Pseudo-chrysolite, synonym of moldauite, bouteillenstein.

Pseudomorph, the replacement of one mineral by another, such that the form of the first is preserved by the second, despite the difference in composition.

Puddingstone, conglomerate.

Pulaskite, a special name given by J. Francis Williams to certain syenitic rocks from Pulaski County, Arkansas, that have trachytic texture and that consist of orthoclase (kryptoperthite), hornblende (arfvedsonite), biotite and a little augite (diopside), eleolite, sodalite and accessory minerals. Ann. Rep. Geol. Surv. Ark., 1890, II., 56. Compare laurvikite.

Pumice, excessively cellular, glassy, lava, generally of the composition of rhyolite. See p. 21.

Pyroschists, a name suggested by T. Sterry Hunt for those sediments that are impregnated with combustible, bituminous matter. Amer. Jour., March, 1863, 159.

Pyroxene. The name of the mineral is often prefixed to the name of the rocks that contain it.

Pyroxenite, a name first proposed by T. Sterry Hunt for the masses of pyroxene occurring with the apatite deposits of Canada. It is now generally employed in the sense advocated by G. H. Williams for granitoid, non-feldspathic rocks, whose chief mineral is pyroxene, and which lack olivine. See p. 51. (Amer. Geologist, July, 1890, p. 47.) Williams proposed the name websterite, from Webster, N. C., for a variety consisting of diopside and bronzite, with the latter porphyritically developed. Idem., 35.

Q

Quartz, the name of the mineral is prefixed to the names of many rocks that contain it, as quartz-porphyry, p. 24; quartz-trachyte, p. 24, etc.

Quartzite, metamorphosed sandstone. See p. 106. Not to be used for vein quartz.

R

Reaction-rims, a term mostly used in microscopic work, for the curious rims of hypersthene, garnet, hornblende, biotite, magnetite and perhaps other minerals, that surround grains of magnetite or of ferromagnesian silicates wherever, in many gabbros they come next to feldspar. They are supposed to be produced by the reaction of the minerals on each other, probably in the crystallization of the rock. (See J. F. Kemp, Bull. Geol. Soc. of Amer., V. 221, 1894).

Regional-metamorphism, Daubree's name for that extended metamorphism, that, as contrasted with contact effects, is manifested over large areas See pp. 85–93.

Rensselaerite, E. Emmons' name for a talcose rock from St. Lawrence Co., N. Y. Annual Report of the N. Y. Geol. Survey, 1837, p. 152.

Resorbed, a term used in microscopic work to describe those phenocrysts which after crystallization are partially fused again into the magma. See p. 17.

Retinite, the current name for pitchstone among the French.

Rhomben-porphyries, a name applied to certain Norwegian porphyries, whose phenocrysts of orthoclase are bounded by ∞P and $2P\infty$, so that they resemble a rhombohedron. The orthoclase is rich in soda.

Rhyolite, volcanic rocks, of porphyritic or felsitic texture, whose phenocrysts are prevailingly orthoclase and quartz, less abundantly biotite, hornblende or pyroxene, and whose groundmass is crystalline, glassy, or both. The name is from the Greek to flow, and refers to the frequent flow structure. Rhyolite is current in America, whereas liparite and quartz-trachyte are more used abroad. The name was given in 1860 by v. Richthofen. (Jahrb. d. k. k. Reichsanst, XI., 153, 1860).

Rill-marks, small depressions in sandstones, produced by the eddying of a retreating wave on a seabeach under the lee of some small obstruction such as a shell or pebble.

Ripple-marks, corrugations in sandstones produced by the agitation of waves or winds when the rock was being deposited.

Rock-flour, a general name for very finely pulverized rocks or minerals which lack kaolin and, therefore, the plasticity of clay, and which are much finer than sand. Rock-flour which is largely pulverized quartz may be separated from most clays.

S

Saccharoidal, a textural term applied to sandstones that resemble old-fashioned loaves of sugar.

Sagvandite, a curious rock from near Lake Sagvand, Norway, that is mainly bronzite and magnesite. A little colorless mica, and more or less chromite and pyrite are also present. The name was given by Pettersen. Neues Jahrb., 1883, II., 247.

Sahlite, a variety of pyroxene, sometimes prefixed to rock names.

Salband, a term current among miners for the parts of a vein or dike next to the country rock.

Sand, incoherent fragment of minerals or rocks of moderate size, say one-quarter of an inch (6 mm.) and less in diameter. Quartz is much the commonest mineral present. See p. 63.

Sandstone, consolidated sand. See p. 63.

Sanidinite, a name applied especially to certain trachytic bombs that occur in tuffs in the extinct volcanic district of the Laacher See, Germany. Recently it has been suggested by Weed and Pirsson for those syenitic rocks which are all orthoclase. Amer. Journ. Sci. Dec., 1895, p. 479.

Sanukite, Weinschenk's name for a glassy phase of andesite that contains bronzite, augite, magnetite, and a few large plagioclases and garnets. They are related to the andesites as are the limburgites to the basalts. Neues Jahrb. Beilageband, VII., 148, 1891.

Saussurite-gabbro, gabbro whose feldspar is altered to saussurite. See p. 103.

Saxonite, Wadsworth's name for peridotites consisting of enstatite or bronzite and olivine. Synonym of harzburgite, but saxonite has priority. Lithological Studies 1884, p. 85.

Schalstein, an old name for a more or less metamorphosed diabase-tuff.

Schiller-fels, enstatite or bronzite peridotite with poicilitic pyroxenes. Orthorhombic pyroxenes possess the poicilitic texture to a peculiar degree, and especially when more or less altered to bastite, and the term schiller, which expresses this, is especially applied to them.

Schillerisation, Judd's name for the process of producing poicilitic texture by the development of inclusions and cavities along particular crystal planes. The cavities are largely produced by solution, somewhat as are etch figures, and are afterwards filled by infiltration. Quart. Jour. Geol. Soc., 1885, 383; 1886, 82.

Schist, thinly laminated metamorphic rocks that split more or less readily along certain planes approximately parallel. See p. 99.

Schlieren, a useful German term, largely adoped into English, for those smaller portions of many igneous rocks which are strongly contrasted with the general mass, but which shade insensibly into it. Thus portions of granite are met, much richer in biotite and hornblende than the normal rock, or much more coarsely crystalline. Pegmatite streaks occur and other differentiations of the original magma. Several different varieties may be made, for a discussion of which see Zirkel's Lehrbuch der Petrographie, I., 787, 1893.

Schorl, an old name for tourmaline, still sometimes used in names of rocks.

Scoria, coarse, cellular lava, usually of basic varieties.

Scyelite, Judd's name for a rock, related to the peridotites, that occurs near Loch Skye, in Scotland. Its principal mineral is green hornblende, presumably secondary after augite; with it is serpentine, supposed to be derived from olivine, and a bleached biotite. See Q. J. G. S., 1885, 401.

Secondary, a term used both for rocks and minerals that are derived from other rocks or minerals, such as sandstone, clay, or other sediments; chlorite from augite, etc.

Sedimentary, rocks whose components have been deposited from suspension in water. See p. 60.

Selagite, a name of Hauy's for a rock consisting of mica disseminated through an intimate mixture of amphibole and feldspar, but it has been since applied to so many different rocks as to be valueless.

Selenolite, Wadsworth's name for rocks composed of gypsum or anhydrite. Rept. State Geol. of Mich., 1891–92, p. 93.

Septaria, literally little walls, a name applied to concretions, largely of argillaceous material which are traversed by cracks. The cracks are filled as a rule with calcite or quartz, affording an intersecting network from which weathering may have removed the original, included, argillaceous matter.

Sericite-schist, mica-schist whose mica is sericite. See p. 100. Sericite is also used as a prefix to many names of metamorphic rocks containing the mineral.

Serpentine, a metamorphic rock consisting chiefly of the mineral serpentine. See p. 113.

Shastalite, Wadsworth's name for unaltered glassy forms of andesite. Rept. of Mich. State Geol., 1891–92, p. 97.

Shonkinite, a name given by Weed and Pirsson to a rock from the Highwood Mountains, Mont., which they define as "a granular, plutonic rock consisting of essential augite and orthoclase, and thereby related to the syenite family. It may be with or without olivine, and accessory nepheline, sodalite, etc., may be present in small quantities." Bull. Geol. Soc. Amer., VI., 415, 1895. See Anal. 7, p. 34. Later they state that augite should exceed orthoclase. Amer. Jour. Sci., Dec., 1895, p. 479.

Shoshonite, a general name proposed by Iddings for a group of igneous rocks in the eastern portion of the Yellowstone Park. They are porphyritic in texture, with phenocrysts of labradorite, augite and olivine, in a groundmass that is glassy or crystalline; in the latter case orthoclase and leucite, alone or together, are developed. Chemically they range, SiO_2, 50–56; Al_2O_3, 17–19.7; CaO, 8–4.3; MgO, 4.4–2.5; Na_2O_3, 3–3.9; K_2O, 3.4–4.4. The rocks are to be considered in connection with absarokite and banakite. Jour. of Geol. III., 937.

Siderolite, as used by Fletcher and generally in English, a name for meteorites that are partly metallic iron and partly silicates. As used by others it is applied to more purely metallic ones.

Sideromelane, von Waltershausen's name for a basaltic glass from the palagonite tuffs of Sicily. Vulk. Gest. v. Sicilien und Island, 202, 1853.

Silicalite, Wadsworth's name for rocks composed of silica, such as diatomaceous earth, tripoli, quartz, lydite, jasper, etc. Rept. State Geol. Mich., 1891–92, p. 92.

Silicification, the entire or partial replacement of rocks and fossils with silica, either as quartz, chalcedony or opal.

Sillite, Gümbel's name for a rock from Sillberg, in the Bavarian Alps, variously referred by others to gabbro, diabase, mica-syenite and mica-diorite. Beschr, der bay. Alpen, 184, 1861.

Sills, an English name for an intruded sheet of igneous rock.

Silt, a general name for the muddy deposit of fine sediment in bays or harbors, and one much employed in connection with engineering enterprises.

Sinaite, an alliterative substitute for syenite proposed by Rozières because on Mt. Sinai true, quartzless syenites occur, whereas at Syene the rock is a hornblende-granite. See p. 35.

Slickensides, polished surfaces along faults, or fractures produced by the rubbing of the walls upon each other during movement.

Soapstone, metamorphic rocks, consisting chiefly of talc. See p. 114.

Soda-granite, granites especially rich in soda, or whose soda exceeds the potash. Compare analyses, p. 30. See natron-granite.

Sodalite-syenites, syenites rich in sodalite; close relatives of nepheline syenites. See anal. 5, p. 34. Sodalite-trachytes also occur.

Soil, surface earth mixed with the results of the decay of vegetable or animal matter, so as usually to have a dark color.

Sölvsbergite, Brögger's name for quartzless or quartz-poor grorudites, that is, medium to finely crystalline dike rocks, with prevailing alkali-feldspar (mostly albite and microcline) with ægirine, or in the basic varieties with hornblende (kataforite), sometimes also with a peculiar mica. In the most basic members quartz entirely fails and nepheline appears. (Die Eruptivgesteine des Kristianiagebietes, I., 67.)

Sondalite, a name proposed by Stache and von John for a metamorphic rock consisting of cordierite, quartz, garnet, tourmaline and cyanite. Jahrb. d. k. k. g. Reichsanst, 1877, 194.

Sordawalite, an old name for the glassy salbands of small diabase dikes that were regarded as a mineral. It is derived from Sordawalar, a locality in Finland. Compare wichtisite.

Spheroidal, a descriptive term applied to igneous rocks that break up on cooling into spheroidal masses, analogous to basaltic columns; also used as a synonym of orbicular as applied to certain granites.

Spherulites, rounded aggregates or rosettes, large or small, of acicular crystals that radiate from a centre. They are chiefly met in the microscopic study of acidic, volcanic rocks and commonly consist of feldspars and quartz. When of one mineral they are called by Rosenbusch sphero-crystals. They may reach large size, though mostly microscopic. See p. 21.

Spilite, an early French name for dense, amygaloidal varieties of diabase.

Spilosite, a spotted contact rock produced from shales and slates by intrusions of diabase. They correspond to the hornfels of granite contacts. Zincken in Karsten und v. Dechen's Archiv., 1845, 584.

Stalactite, depending columnar deposits, generally of calcite, formed on the roof of a cavity by the drip of mineral solutions. Compare stalagmite.

Stalagmite, uprising columnar deposits, generally of calcite, formed on the floor of a cavity by the drip of mineral solutions from the roof. Compare stalactite.

Steatite, soapstone, talc rocks.

Structure, used generally in America for the larger physical features of rocks,as against *texture*, which is applied to the smaller ones. See p. 13. Many, however, employ them interchangeably. Compare also petrical and lithical.

Stylolite, small columnar developments in limestones or other calcareous rocks that run across the stratification. They appear to have been caused by some unequal distribution of pressure in consolidation, or by a capping fossil, as against the surrounding rock.

Subsoil, the layer of more or less decomposed and loose fragments of country rock that lies between the soil and the bed rock in regions not covered by transported soils.

Suldenite, a name given by Stache and von John to gray acidic, andesitic porphyrites in the eastern Alps. The range from 54–62 SiO_2 and have in the prevailing gray groundmass phenocrysts of hornblende, plagioclase, a little orthoclase and accessory augite, biotite and quartz. Compare ortlerite.

Surficial, a general name lately introduced by the U. S. Geological Survey, for the untransported surface, alteration products of igneous rocks.

Sussexite, a special name suggested by Brögger for the eleolite porphyry, originally described by Kemp, from Beemerville, Sussex Co., N. J. Die Eruptivgesteine des Kristianiagebietes, 1895. The name was, however, applied years ago to a ~~borosilicate~~ from Franklin Furnace, N. J.
hydrated borate

Syenite, granitoid rocks consisting in typical instances of orthoclase and hornblende. In mica-diorites, biotite replaces hornblende. In augite-syenites augite does the same. For etymology and history see p. 36. Compare also laurvikite, monzonite, nordmarkite, pulaskite, sanidinite, shonkinite, yogoite.

Syssiderite, Daubrée's name for those meteorites which consist of silicates cemented together by metallic iron.

T

Tachylyte, Breithaupt's name for a basaltic glass. It was originally regarded as a mineral and was named from two Greek words suggested by its quick and easy fusibility. See analysis 15. p. 20, and description p. 21. Kastner's Archiv. für die gesammte Naturlehre, VII., 112, 1826. Compare hyalomelane.

Taconyte, a name proposed by H. V. Winchell for the cherty or jaspery but at times calcareous or more or less quartzitic rock that encloses the soft hematites of the Mesabi Range, Minn. They are regarded as in large part altered greensands by J. E. Spurr. The term is current in the Mesabi iron range. XX. Ann. Rept. Minn. Geol. Survey, 124. The name is derived from Taconic, E. Emmons' rejected geological system.

Talc-schist, schistose rocks consisting chiefly of talc and quartz. See p: 104. Talc is also prefixed to several other rock names.

Taxite, Loewinson-Lessing's name for lavas that on crystallizing have broken up into contrasted aggregates of minerals so as to present an apparent clastic structure—either banded, *i. e.*, eutaxitic, or brecciated, *i. e.*, ataxitic. Bull. Soc. Belg. Geol., V., 104, 1891.

Tephrite, basaltic rocks containing lime-soda feldspar, nepheline, augite and basis. Leucite-tephrites have leucite in place of nepheline, and some tephrites have both. Tephrites differ from basanites in lacking olivine. The name is from the Greek for "ashen," alluding to the color. It is an adaptation of an old form tephrine. Neues Jahrb., 1865, 663.

Teschenite, a name given in 1861 by Hohenegger to a group of intrusive rocks in the cretaceous strata near Teschen, Austrian Silesia. They have, however, been since shown to embrace such a variety of types that the name has little value, but as analcite occurs quite constantly in most of them, many still use the term for diabasic rocks with this mineral.

Texture. See structure and also p. 13.

Theralite, granitoid rocks consisting essentially of plagioclase, nepheline and augite, with the common accessories. They were first discovered by J. E. Wolff in the Crazy Mountains, Montana. They were previously prophetically named by Rosenbusch from the Greek to seek eagerly, because this mineralogical and textural aggregate was believed to exist before it was actually discovered. A spelling therolite is also advocated.

Tholeite, Rosenbusch's name for augite-porphyrites, which, aside from the usual phenocrysts, have a groundmass, with but one generation of crystals and with a little glassy basis between them, affording a texture called intersertal. Massige Gest., 504, 1887.

Till, unsorted glacial deposits, consisting of boulders, clay and sand.

Timazite, a name given by Breithaupt to certain porphyritic rocks in the Timok Valley of Servia, that have since proved to be varieties of andesite and dacite. Berg. und Hüttm. Zeit, 1861. 51.

Toadstone, an old English name for certain intruded sheets of amygdaloidal basaltic rocks in the lead district of Cumberland, England. Also locally applied near Boston to a mottled felsite, apparently spherulitic.

Tollite, a biotite, hornblende, porphyrite, with garnets, that forms dikes in mica-schist and gneiss near Meran, in the Tyrol. Pichler, Neues Jahrb. 1873, 940.

Tonalite, a quartz-mica-hornblende diorite from near Meran in the Tyrol. It was named by vom Rath. from Tonale, a place on Mt. Adamello. Zeit. d. d. g. Gesellsch. XVI., 249, 1864. Compare adamellite.

Topazfels, a brecciated, contact rock, near granite contacts, and formed of topaz, tourmaline, quartz and some rarer accessory minerals.

Touchstone. See basanite.

Tourmaline-granite, a variety of granite with tourmaline as the dark silicate. It is usually due to fumarole action and is developed on the borders of intrusions of normal granites.

Trachorheite, a name proposed by F. M. Endlich as a collective designation for the four rocks, propylite, andesite, trachyte and rhyolite, as used by von Richthofen. Hayden's Reports, 1873, p. 319.

Trachyte, volcanic rocks of porphyritic or felsitic texture consisting essentially of orthoclase and biotite or hornblende or augite, one or more. See p. 27. It was formerly used for both rhyolites and trachytes proper, or practically as a field name for light colored lavas and porphyries. As such in older reports it is to be understood. Compare also acmite-trachytes and pantellerites.

Trachytic structure, a special microscopic name for those groundmasses that are made up of rods of feldspar, usually in flowlines, but without basis.

Trap, a useful field name for any dark, finely crystalline igneous rock. It is a Swedish name from the occurrence of such rocks in sheets that resemble steps, "trappar." See p. 56.

Trass, a trachytic tuff from the Laacher See used along the Rhine for hydraulic cement.

Mass. Gest., 501, 1887. Wadsworth uses the name for an altered andesite glass. Rept. of State Geol. of Mich., 1891–92, p. 97.

Whinstone, a Scotch name for basaltic rocks.

Wichtisite, a glassy phase of diabase, named from a Finland locality, Wichtis. Compare sordavalite.

X

Xenogenites, Posepny's term for mineral deposits of later origin than the wall rock. The name means foreigners, and refers to their later introduction. Compare idiogenites. Trans. Amer. Inst. Min. Eng., XXIII., 205, 1893.

Xenomorphic, Rohrbach's textural name for those minerals in an igneous rock whose boundaries are determined by their neighbors. Its antithesis is automorphic, which see. Xenomorphic is synonymous with allotriomorphic, over which it has priority. Tsch. Mitt., 1886, 18.

Y

Yogoite, a name suggested by Weed and Pirsson from Yogo peak, one of the Little Belt Mountains, Mont., for a syenitic rock composed of orthoclase and augite in about equal amounts. See also sanidinite and shonkinite. Amer. Jour. Sci. Dec., 1895, 473–479.

Z

Zircon-syenite, a name originally given by Hausmann to certain Norwegian nepheline syenites which were rich in zircons. Later it was practically used as a synonym of nepheline syenite, but is now obsolete.

Zirkelite, a name proposed by Wadsworth in 1887 to designate altered basaltic glasses, in distinction from their unaltered or tachylitic state. Geol. Surv. Minn. Bull. 2, 1887, p. 30.

Zobtenite, Roth's name for metamorphic rocks with the composition of gabbros, *i. e.*, rocks not certainly igneous. The name is derived from the Zobtenberg, a Silesian mountain. Sitz. Berl. Akad., 1887, 611.

Zonal-structure, a term especially used in microscopic work to describe those minerals whose cross-sections show their successive, concentric layers of growth.

Zwitter, a Saxon miner's term for a variety of greisen. Only of significance in connection with tin ores.

INDEX.

NOTE.—The index only concerns the main portion of the book and not the Glossary. Attention may be called to the latter as embracing many rocks not otherwise mentioned.